AFIT/GSO/ENS/88D-20

DTIC FILE COPY

AD-A202 597

DTIC
S ELECTE JAN 1 8 1989 D
D

A HEURISTIC APPROACH FOR

AEROMEDICAL EVACUATION SYSTEM

SCHEDULING AND ROUTING

THESIS

W. Tod Whetstone
AFIT/GSO/ENS/88D-20 1Lt USAF

Approved for public release; distribution unlimited

89 1 17 133

AFIT/GSO/ENS/88D-20

A HEURISTIC APPROACH FOR AEROMEDICAL EVACUATION SYSTEM SCHEDULING AND ROUTING

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by
W. Tod Whetstone, B.S.
First Lieutenant, USAF

December 1988

Approved for public release; distribution unlimited

Preface

I am grateful for this opportunity to give thanks to all of those who have given me help and support through out the process of writing this thesis. This thesis could not have been accomplished if it were not for the help of my advisor, Dr. James W. Chrissis. He has given much needed comments and guidance. I would also like to give thanks to Major Joseph R. Litko, my reader. He provided additional comments to make this a well written and professional looking document.

This thesis would not even have been accomplished if it were not for Major Mark Donnelly. He presented me with the original idea for this thesis. Furthermore, he assisted me by getting all pertinent data for the aeromedical evacuation system as well as letting me know about several helpful literature sources.

Finally, I would like to thank my wife, Jamie Lee Whetstone. If it were not for her considerable understanding and caring I may have given up long ago. She gave me the motivation to continue researching the problem and writing the document on several occasions.

Contents

Contents (Cont'd)

List of Figures

List of Tables

List of Tables (Cont'd)

AFIT/GSO/ENS/88D-20

Abstract

This thesis formalizes and applies a heuristic approach to the aeromedical evacuation system (AES) weekly scheduling problem. The study also examines algorithms that could be applied to the daily routing problem of the AES.

The study had three basic objectives: 1) Present a formal model that can be used to develop the weekly schedule that is used by the AES. 2) Compare the utility of having a fixed weekly as opposed to a flexible weekly schedule. 3) Examine the daily routing problem of the AES and point out major difficulties in solving the daily routing problem.

This thesis found that a formal model can be utilized to solve for a weekly schedule. However, it was also discovered that the fixed weekly schedule is not the primary obstacle in the AES routing and scheduling problems. The patient demands change continuously from day to day and week to week etc..., so it is not possible to develop a schedule that will be optimal for all days of the scheduling period.

Furthermore, the daily routing problem continued to be the problem that requires substantial attention. Therefore, a model is formulated that may be used to (cont'd)

Cont'd

determine the daily routing of the AES. This model is an integer (0-1) program.

A HEURISTIC APPROACH FOR

AEROMEDICAL EVACUATION SYSTEM

SCHEDULING AND ROUTING

I. Introduction

Introduction

Routing design problems occur in many situations concerning delivery or collection. Refuse collection, mail collection and delivery, and various other transportation and distribution systems are examples of vehicle routing problems (VRP). There are several types of VRPs that can be applied to different circumstances and conditions. In particular there are:

1. daily routing -- a set of vehicle routes have to be developed each day, for a specific set of conditions.
2. period routing -- a set of vehicle routes have to be developed to meet a customer's recurring demand.
3. fixed routing -- a set of vehicle routes have to be developed to operate unchanged over a period of time. (2:49)

A fourth type of VRP is the assignment routing problem. The assignment routing problem is a VRP in which the main objective is to assign vehicles to the customer demand points for various days of the week. The vehicles may be assigned to either regional areas or population centers. Through this, the problem is reduced to the

daily routing problem for each day of the service period.

This thesis focuses on developing an assignment routing heuristic and then applying it to determine an improved weekly schedule for the aeromedical evacuation system (AES). The AES is like any other transportation system in that the AES must pick up and deliver patients throughout six geographical medical regions using a finite number of aircraft.

Scope

The scope of this thesis topic has been limited to improving the weekly schedule of the AES serving the continental United States (CONUS). Additionally, the vehicle routing problems that are modeled have been limited to the assignment routing problem and the daily routing problems previously described.

The concepts underlying the assignment routing problem are used to develop a heuristic approach to improving the AES weekly schedule. Since this heuristic method, like many other heuristic models, involves much subjectivity, modifications may be required to satisfy different users. These modifications should be minor and relatively simple to implement. The model herein uses historical patient demands in order to determine an improved schedule. The improvement is based on the increase in total patients served by the AES as well as the decrease in aircraft flying hours. These represent improved quality of service

and reduced cost, respectively.

Modifications to the assignment algorithm and patient demand frequency are used to perform a sensitivity analysis on the improved schedule. This analysis determines how well the improved schedule reacts to dynamic changes in demand within the AES. These dynamic changes include increases to the patient demands for inter- as well as intra-regional medical service. Additionally, inter- and intra-regional patient transfers are varied to determine the overall effect on the weekly schedule. Improvement in the new schedule is based on minimizing flying hours and patient overnight stops as compared to the initial schedule.

Problem Statement

Major Mark Donnelly from HQ MAC/AG presented this thesis topic because current AES operations are costly and leave several people, including patients and physicians as well as personnel from the AES, dissatisfied. The main thrust of the problem is to improve the movement of patients through the AES within specified time standards while limiting the number of overnight enroute delays (RON) once the patients are in the system. This can be accomplished by determining the optimal routes and weekly schedules to be used by the AES.

Objectives

The main thrust of this thesis is to develop a heuristic approach to solving the assignment problem with fixed routing and periodic customer demands within the operating confines of the AES. The model should be extendable to any problem in which vehicles are alloted to specific regions or populations on a periodic basis based on customer demand for service. Very little attention has been given to the assignment problem with fixed routing and periodicity; therefore, few models exist that could be applicable to this type of VRP.

Research indicates that benefits can be obtained by developing and applying a systematic approach to assignment problems (2:49). The area for greatest improvement appears to be choosing assignments to meet service level requirements. For this reason a significant weight is given to frequency of demand in applying the assignment model.

This thesis develops an improved weekly schedule that is used in routing patients through the AES by developing and implementing a heuristic methodology for the assignment problem. This weekly schedule includes the routes to be taken by the various aircraft each day of the week. The algorithm could also have been used to improve the existing weekly schedule instead of developing a completely new schedule.

Additionally, a sensitivity analysis is carried out to illustrate how the proposed routes and schedules react to dynamic influences (priority or urgent patients as well as user subjectivity) to the system. This sensitivity analysis involves a model that is developed for the various conditions that are particular to the AES. These conditions include:

1. multi-vehicle -- more than one aircraft could service a particular region.
2. multi-depot -- the aircraft do not always take off and land at the same medical facility.
3. precedence relationships -- the patients must be picked up before they can be delivered.
4. partial/incomplete service -- not all patients are served the same day due to restrictions on the aircrews.

A study of the benefits provided by the new routes is also included. According to Major Donnelly, several organizations would benefit from improved routing. MAC/XPPB believes that improved routing would reduce the C-9 flying hours. Since C-9 flying hours are currently costed at $1000 per hour, a reduction in flight time could save a considerable amount of money (5:2).

The medical service officers feel that improved routing would improve the service offered to the patients. Currently, 30% of all patients in the system require a RON, including 10% of the patients requiring more than one RON (5:2). Also, since it is impossible to service all medical facilities using limited aircraft and crews, some

facilities must transport patients for up to three hours to airfields serviced by the AES (5:2). Therefore, improved routing to the medical service officers would include providing service to more airfields or at least reduce the driving time to reach an airfield.

The 375th AAW would also benefit from improved routing, especially if it saves flying hours. The 375th AAW would like to use any excess flying hours for exercises in order to better prepare their crews for their wartime mission (5:2).

Currently the Patient Airlift Center (PAC) routes all daily traffic manually. PAC starts with a fixed weekly schedule that gives the starting point, region to be serviced and the final destination. Then, by looking at the patients currently in the system, an experienced scheduler routes the missions to service the patients. The scheduler benefits if the weekly schedule is designed so that the optimal routes given patient demand is considered. This enables the scheduler to make as few changes to the schedule as possible and still satisfy all patient requests. An improved schedule also permits the scheduler to most efficiently route the aircraft on a daily basis.

Methodology

Improving the routing of the AES is the primary goal of this study. This is accomplished by generating a weekly

schedule that improves the overall performance of the system by reducing the number of patient RONs and total aircraft flying hours. The first step in this process consists of reviewing current algorithms and computer models that are candidates to be used in the improvement phase.

The AES scheduling problem has certain qualities in common with assignment routing problems. Therefore, a significant portion of the research concentrates on methods that produce valid solutions to various modifications of this class of problems. More specifically, a determination is made as to how applicable these approaches are with respect to the specific requirements of the AES scheduling problem.

This research forms the foundation from which the heuristic method is developed and applied to the AES. The basis for the model is a summary of the frequency of patient transfers for each day of the week. The transfers include inter- as well as intra-regional service. The historical data that is used in this model was provided by HQ MAC/AG in conjunction with the PAC.

The historical patient demands are then varied to different extremes. This shows the flexibility of the improved schedule and also determines what happens to the schedule when changes in demand are placed on the system. There are two major variations imposed on the schedule.

First, the inter-regional patient transfers are increased while holding intra-regional transfers constant. The second variation involves holding the inter-regional patient transfers constant while increasing the intra-regional transfers.

The second phase of the study considers the system's response to dynamic influences. That is, the impact of priority or urgent patients on the overall system is determined. This shows how adequately the new schedules can accommodate changes due to new patients input to the system. More specifically, it indicates whether the system can still perform its primary mission, the expedient movement of all patients, when priority or urgent patients enter the system.

This sensitivity study is carried out over various changing conditions in order to establish valid comparison criteria. This is necessary for two reasons. First, a schedule that is initially determined to be an improvement may not be capable of adjusting to the dynamic influences. This may cause the routes and schedules to become infeasible. Secondly, it shows how well the system can accommodate changes in customer demands, and indicates the conditions under which the schedule breaks down.

Assumptions

The fundamental assumption is that patient demand is static. That is, the heuristic model that is used in

improving the AES weekly schedule has a basis on historical data. This data is used as a foundation on which the various aircraft are assigned to the medical regions. Even though this data does change from week to week, it is assumed to be constant in order to develop an improved schedule.

The daily routing problem is examined to determine how the improved schedule compares to the current schedule. This comparison is based on minimizing patient RONs and total flight time. In order to determine the time to fly from one medical facility to another, an average or predictable flight time is taken. Additionally, the time on ground is to be determined for each medical facility.

The initial assumption concerning the AES operations is that the system is operating under peacetime conditions. While the primary mission of the AES is to provide patient movement during wartime, the system also has several peacetime objectives. These objectives include being able to:

1. provide expansion capability for the wartime mission.
2. conduct realistic wartime training for the aeromedical crews.
3. support the efficient concentration of specialized medical resources.
4. reduce the requirements for overseas medical facilities.
5. aid civilian disaster relief efforts. (1:64)

Therefore, various benifits are achieved by obtaining an improved routing under peacetime conditions.

Additional assumptions that have been identified pertain to the model that is used to solve the problem. First, the aircraft involved all have the same capacity and performance characteristics (i.e. range, speed). This is a valid assumption since the C-9 aircraft are the primary vehicles used in transporting patients. The C-141 and C-130 aircraft are not included in the study since the C-141 fly missions primarily overseas and along intercontinental routes and the C-130 fly only a few missions along shorter routes.

Secondly, only the routes for the CONUS are considered. Although the system does receive patients from overseas they arrive primarily to either Travis or Andrews Air Force Bases (14:113) and then become part of the CONUS AES. For this analysis it is assumed that all overseas patients originate at one of these two bases.

Outline of Subsequent Chapters

Chapter II reviews the background of the AES. This includes the mission, current scheduling procedures, goals and expectations of the system. Chapter III addresses heuristic approaches that can be used to assign AES aircraft to the six medical regions. Additionally, a heuristic algorithm is developed and applied to the AES in order to improve the current schedule. Algorithms that could be applied to the daily routing problem are examined in chapter IV. Sensitivity of the daily routing problem

is also discussed.

Chapter V summarizes the algorithms and heuristics previously discussed as well as their applications to the AES. Recommendations are also given for areas of further research. Moreover, comments on the current AES scheduling procedure are given.

II. AES Background

Introduction

Aeromedical transportation has been in existence for more than 100 years. Balloons were used during the seige of Paris in 1870 (14:13). Aircraft were not used to transport patients until during World War II. Currently a variety of aircraft are used in transporting patients. These aircraft range from converted transport planes to helicopters.

There have been many other changes to aeromedical transportation systems. These changes include purposes, types of services provided and number of patients transported (14:15). This study concentrates on the DoD's AES. It is the largest and most experienced aeromedical transportation system in existence (14:15). The majority of systems service a city, state or at most a few states. The AES services the entire United States as well as overseas bases. Furthermore, the AES handles approximately 5000 cases per month. The combined effort of other hospital-based aeromedical systems is about fifty percent of the total number of patients handled by the AES (in 1981) (14:16).

The remainder of this chapter is a brief overview of the AES. This overview includes the AES mission, scheduling procedures, goals and objectives. An Air

University research report, TOWARD A HEALTHIER AEROMEDICAL OPERATION, and Lt Col D.R. McLain's PhD dissertation, A SYSTEMS APPROACH TO THE AEROMEDICAL AIRCRAFT ROUTING PROBLEM USING A COMPUTER BASED MODEL, are recommended for a more detailed discription of the AES.

Mission Description

The mission of the AES is to transport patients, using eighteen C-9 aircraft (twelve aircraft in the continental U.S.), to and from medical facilities where the patients receive required treatment. The C-9 aircraft are equipped to provide all the care necessary for up to forty patients (5:1). Additionally, a few C-141 aircraft and C-130 aircraft are used to assist on a variety of missions.

The primary patients of the system are active-duty members of the military; however, all eligible dependents, retirees and dependents of retirees may also use the system as long as the primary mission is not affected. The mission would become degraded if active-duty military members were not served due to an excessive amount of other patient traffic in the system. Furthermore, any delay in returning the military members back to their official duties is considered a degraded situation.

Some patients that use the system may also have attendants. These attendants may be medical (doctors, nurses or technicians) or non-medical (family or friends)

(5:1). The patients that use the aeromedical evacuation system have various medical needs. These individuals are transported to the closest facility that can meet those needs. One problem that exists with the current system is that some medical facilities are not served by the aircraft since they do not have adequate airfields nearby. The patients stationed at or near these medical facilities must be driven, sometimes for as long as three hours, to medical facilities that are serviced by the system (5:2).

The patients may be inpatients or outpatients; they may be ambulatory or on a litter (5:1). All patients, regardless of their condition, can be classified into one of the following categories:

1. Routine -- the most common category. These patients must be transported within seventy-two hours.
2. Priority -- these patients require movement within twenty-four hours.
3. Urgent -- these patients must receive immediate medical attention.

(5:1)

There is an additional category which is an extension of the routine, priority or urgent patient classifications. This extension is classified as special (5:1). For example, a patient may not be in the urgent category, but must be delivered to a medical facility with dialysis support without delay. This patient would be classified as special. Even though he may not be in the priority or urgent category, his special needs require that he be treated as a priority or urgent patient for scheduling

purposes.

Finally, there are several other factors that influence the routing and scheduling problem. Occasionally, the AES has some intercontinental missions. These missions must be handled so that they will not interfere with the normal routes in the CONUS. An additional restriction that is placed upon the routing and scheduling problem concerns the crew's well-being. Regulations allow only eight stops per mission to reduce crew fatigue. Additionally, the crews are limited to sixteen-hour duty days (5:1). This limit starts two hours prior to their first takeoff.

Scheduling Procedure

Currently, the AES has the CONUS divided into six regions. Assigned to each region is an aeromedical staging facility (medical center) that is used to determine the nodes that connect the various routes. According to McLain, no one in the AES knows the reason for these medical facilities being designated as staging facilities (14:115). However, these facilities do have the following characteristics:

1. they are minimum-care facilities.
2. they are located at points that function as origins and destinations for patient movements, intra- and interregional transfer points, and overnight stopovers for crews and aircraft.
3. two (Travis and Andrews) receive patients from overseas.

4. wartime reserve mobilization would activate four more facilities at other Airlift Command bases. (14:113)

Figure 1 shows where the six geographical regions in the CONUS, as well as the corresponding medical centers, are located. The Patient Airlift Center is centrally located at Scott AFB in region six.

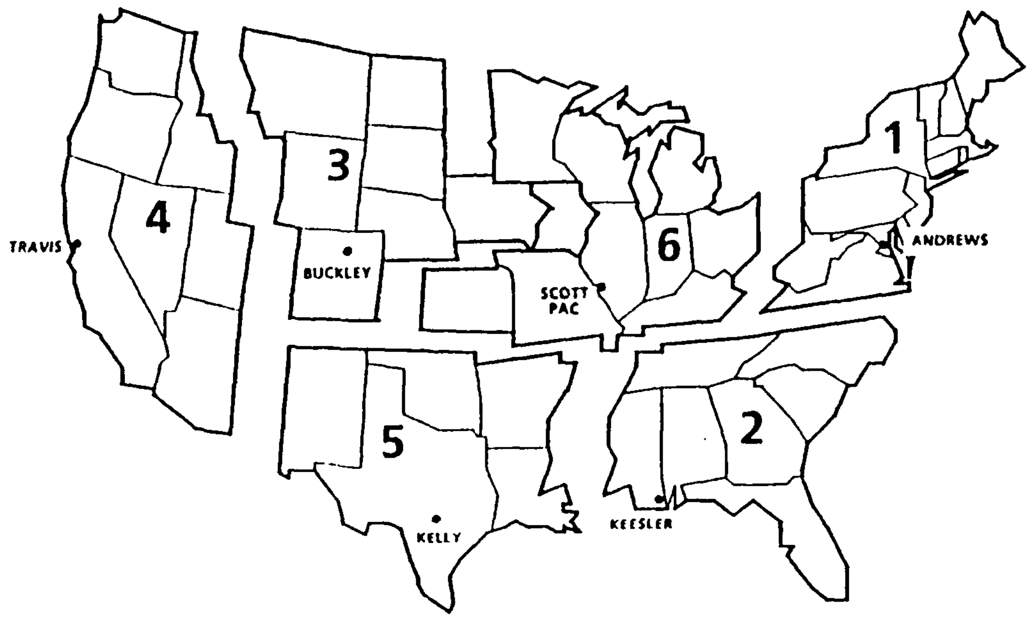

Figure 1. Six Aeromedical Evacuation System Regions (5:3)

The weekly schedule is the skeleton with which the scheduler begins assigning aircraft missions, this includes the mission origin and destination as well as the region

to be serviced. Table I shows the current fixed weekly schedule that is used by the AES and Patient Airlift Center schedulers to pick up and deliver patients throughout the CONUS.

Table I

Current AES Fixed Weekly Schedule (5:3)

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0126		0634	0444	0456		0621
		0666	1614	0436	0666	
0654	0456	0654	1416		0634	1416
0663	0336		0636	0663	0336	
06X6	0656		0655	0526	0655	0526
0622	0222	0256		0622	0256	06X6
	0636	0621	0126		1614	0456
06X1	0111	0116		0611	0116	

For example, mission 0621 begins in region 6 (Scott AFB), goes to region 2 (Keesler AFB) and terminates in region 1 (Andrews AFB). Most mission numbers begin with a 0. If a mission number begins with a 1, it is an indication that the mission is cross-country.

Since the crew is limited to eight stops, and two are already scheduled on the weekly schedule, the scheduler must examine the patient requests for that day and determine where the other six, at most, stops will be

located.

Goals and Expectations

The previous section discussed the mission of the AES and how it accomplishes that mission. This section examines the expectations of three of the systems policy makers: the Department of Defense (DoD), the Air Force, and the Military Airlift Command (MAC).

Lee wrote that the DoD expects the AES to "provide expeditious air transportation for sick, injured, and wounded active duty members of the Armed Forces." (1:50) Additionally, all eligible beneficiaries may use the system as long as the primary mission is not degraded. The DoD does not clearly distinguish their expectations in terms of wartime or peacetime; however, Dr. Robert F. Futrell, an Air Force historian, believes that the DoD's peacetime expectations have been defined. The reason for peacetime operations, according to Futrell, is to maintain a state of readiness for expanded air transport services in times of war (1:50).

The Air Force's primary expectation of the AES is to support the war effort (1:51). However, the Air Force also has very specific expectations of the system during peacetime. In addition to sustaining force readiness, the system must have the capability to support:

1. total force structure in times of contingencies.
2. medical crew exposure and experience

with real patients to maintain qualification and proficiency.

3. patients arriving from overseas who require further movement within CONUS.
4. over 650 federal medical facilities with frequent stops.
5. urgent and priority patients requiring life, limb, or sight-saving care when the required care is not available locally.

(1:51)

MAC has primary responsibility for the AES (1:52). According to Lee, MAC expects the "mission for peacetime aeromedical evacuation [to be] readiness training that is sustained by exercising the command and control system, training crews, and testing equipment" (1:52). By moving patients during peacetime, the readiness training is obtained.

It is evident that the primary mission for the AES is the wartime movement of patients. However, it is through the peacetime operation of the system that this readiness is attained. In maintaining the high mission readiness, the system must also be capable of expanding to meet any contingencies.

III. The Weekly Scheduling Problem

Introduction

The task of assigning vehicles to population centers or regions is not a true routing problem,rather, it is an assignment problem. Since the daily requirements and patient demands are changing each day, it is impossible to devise a fixed route that will satisfy all customers at all times in an optimal manner. This is particularly true when the population centers or regions are large. For instance, a route can be determined for all Mondays. However, if the region the vehicle must serve is large (say, the size of the state of Texas), the customer demands would probably change from month to month. The change in customer demands is even more dynamic when dealing with an aeromedical transportation system because the system is constantly changing. The same set of patients do not require service every Monday!

One approach to solving this problem is to examine the frequency of patient demands. If the average patient demands are used to develop a schedule, the problem is often more effectively solved. This method is analogous to using the method of least squares to fit a line to a group of data. It is not always possible to place every data point on the line, just as it not always possible to serve every customer in every region on a single day. However,

just as the method of least squares finds the "best fit", using the average customer demand determines an improved schedule. This is accomplished by calculating the average number of patients requesting service in each region and for each day of the period. Furthermore, the average number of inter-regional as well as intra-regional patient demands must be examined. Table II shows how the data could be displayed for six regions on a single given day. The data for the remaining days could be represented similarly.

Table II

Patient Demand Matrix

Region	1	2	3	4	5	6	Total
1	P_{11k}	P_{12k}	P_{13k}	P_{14k}	P_{15k}	P_{16k}	P_{1k}
2	P_{21k}	P_{22k}	P_{23k}	P_{24k}	P_{25k}	P_{26k}	P_{2k}
3	P_{31k}	P_{32k}	$P_{33}{}^{k}$	P_{34k}	P_{35k}	P_{36k}	P_{3k}
4	P_{41k}	P_{42k}	P_{43k}	P_{44k}	P_{45k}	P_{46k}	P_{4k}
5	P_{51k}	P_{52k}	P_{53k}	P_{54k}	P_{55k}	P_{56k}	P_{5k}
6	P_{61k}	P_{62k}	P_{63k}	P_{64k}	P_{65k}	P_{66k}	P_{6k}

Hillier (10:9) claims that heuristics have become a very popular method for solving practical problems. By looking at the frequency of patient requests (a heuristic approach), a fast and good, but not necessarily optimal, solution is found. There is no guarantee that the heuristic method will generate the best solution, however;

with changing patients demands it would likely be impossible to develop one schedule that is optimal for all situations. Therefore, this method at least gives a good feasible schedule that can be refined toward optimality.

In determining a weekly schedule to service the various regions, three important aspects must be considered. First, the vehicles are assigned to the regions because of the historical frequency of customer requests. Secondly, the assignment of vehicles to the various regions is fixed; that is, the assignments are often not changed. Once a vehicle is assigned to a region on a given day it remains within or near that region. Finally, the schedule is periodic. The assignment of the vehicles is the same for every Monday that the schedule is employed. This is true of any other day of the week as well.

Literature Review

There is very little appearing in the literature regarding the development of an assignment algorithm to produce a fixed and periodic schedule. More precisely, three articles that specifically cover this material appear.

Beasley (2:49) wrote of fixed route problems. He defines a route as fixed if it operates unchanged for a period of time. There are many problems that require this type of routing. Most problems that involve delivery

vehicles require some type of fixed routing.

The most common problem encountered when solving fixed-route problems is infeasibility (2:50). It is difficult to design fixed routes when customer demand fluctuates; a set of routes may be feasible on six days of the week but become infeasible for the seventh day.

Strictly speaking, a route is either feasible or infeasible on any given day. The main concern is to what degree the route becomes infeasible. For example, a route that slightly violates the constraints, possibly vehicle capacity or range, on two days of the week may be superior to a solution that substantially violates these constraints on only one day (2:50). This is true because in the first situation most of the customers can be serviced anyway, however, the second scenario may make it impossible to service several customers.

Beasley examined three solution methods to calculate fixed routes. All three methods adopt a heuristic approach to solve the fixed-route problem. The first method involves reduction to a single-day problem. This is accomplished by determining the maximum customer demand for each day of the period (2:53). This demand is then used to solve the routing problem. The rationale is that if the problem is solved for the maximum possible customer demand, it will satisfy any other requests. The main problem with this approach is that the routes would tend

to be drastically under-utilized on all days except those of maximum demand (2:53).

The second method introduced by Beasely uses an adapted savings algorithm. This approach involves calculating the distance between all destinations and ranking the distances in descending order of magnitude. The savings is accomplished by minimizing the distance the vehicles must travel. The links between two different destinations are then chosen from this list so as not to create an infeasibility (2:53).

The third algorithm that Beasely examines is modified similarly to the adapted savings algorithm (2:53). The adapted r-optimal algorithm is defined as follows. "A set of vehicle routes is r-optimal if, regarding the set of vehicle routes as a single tour of the customers (with many returns to the depot), no improvement can be found by replacing any set of r interrelated customer links by any other r inter-customer links." (2:53)

Christofides and Beasley (3:237) presented heuristic algorithms for vehicle routing problems over time. These problems are also called period routing problems. The first method presented by Christofides and Beasely uses a cluster algorithm. It is called a cluster algorithm because clusters are formed around customers that are definitely scheduled for each day of the period. After the clusters are formed, a vehicle routing algorithm is

used to solve the daily problem. This method is capable of generating feasible solutions but it does not reduce total distance traveled (during the period) very efficiently (3:241) since it only attempts to minimize the distance between the clusters. The second algorithm that Christofides and Beasely review uses the routes developed by the first method and improves them using the adapted savings algorithm by Beasley (3:241). The third algorithm that Christofides and Beasely use is also a savings algorithm that is introduced by Clarke and Wright in a 1964 issue of Operations Research. The customers are assigned to the days of the period using delivery spacing constraints and then improved using the savings algorithm (3:241-242).

Russell and Igo (15:1) address a heuristic routing algorithm in which customer demand points are assigned to days of the week in order to effectively solve the daily routing problem. This type of problem is similar to the problem addressed by Christofides and Beasley using the cluster algorithm. Of primary importance here is the similarity of this type of problem to the AES problem. The use of heuristics is necessary due to the size, as determined by the number of possible nodes, and the "inherent intractability of node routing problems" (15:1).

The objective of the assignment routing problem is to assign regions or populations to the days of the week in

order to solve the problem of daily routing. Regions are assigned to the days of the week so that total weekly distance traveled is minimized. This is accomplished by setting constraints on customer demand, vehicle usage, vehicle capacity, vehicle range and subjective preferences. For small problems an integer programming approach can be used to determine the optimal solution. However, it is not efficient to use integer programming for larger problems (15:3). The number of possible solutions increases by 2^X, where X is the number of variables. The AES routing problem would involvesome 448 variables if it were formulated as a 0-1 integer program, since each of the eight possible nodes could have seven emanating branches.

Model Development

The development of the following heuristic algorithm is based primarily on the historical frequency of patient demands. Since demand is dynamic, it is unlikely that a true optimal solution over all demand patterns can be obtained. It is possible, however, to find an improved solution using heuristic approaches.

One of the clearest methods for determining the frequency of patient demands is using a NxN matrix similar to Table II where N is the total number of population centers or regions that need to be serviced. The matrices (one for each day of the period) contain all the pertinent information for developing an improved schedule. Summing

the rows of the matrix gives the total customer demand for each of the regions (the term P_{ik} is used herein where i is the region and k is the day). Each sub-element of the matrix is the patient transfer from one region to another (the term P_{ijk} is used for patient demand from region i to region j on day k).

Before developing the algorithm it is necessary to consider the constraining factors. There are four primary constraints that must be including in producing a valid model and several other constraints that aid in producing an improved schedule. Two of these constraints are subjective and determined by the user, while the remaining two are set due to the vehicles available.

Vehicle Constraints. The first constraint dealing with the vehicles is the vehicle capacity. The term C_{nk} is used to denote the capacity of vehicle n on day k. The capacity is assumed to be constant for the AES application. This is a valid assumption since all the C-9 aircraft have the same capacity (40 patients), and the values for all the C_{nk} are the same.

The second constraint that involves the vehicles is the number of vehicles available for each day of the period. This constraint is applicable for all uses of the model: There are only a finite number of vehicles in any inventory and a specific number of them are available for use each day.

Subjective Constraints. The two constraints that are due primarily to the subjectivity of the user are the minimum number of patients required to assign a vehicle to a particular region and the minimum number of patients required to terminate the mission in a region other than the depot. The terms $\tilde{a}_{ik}$ and β_{ijk} are used to denote these values, respectively.

The first patient constraint is required to efficiently assign the vehicles to each region for each day of the period. It would not be desirable to assign a vehicle to a region if it would not be beneficial (i.e. cost effective). By knowing the minimum number of patients required to assign a vehicle to a region ($\tilde{a}_{ik}$) and using the frequency table(s) defined previously, it is possible to effectively assign the vehicles.

Furthermore, it is not always desirable to return the vehicle(s) to the depot each day of the period. It may be more effective to transfer the vehicle to another region or keep it in the same region. Again, this is impacted by the subjective constraint concerning the minimum number of patients required to terminate the mission in a region other than the depot (β_{ijk}). If a region requires service by a sufficiently large number of patients two or more days in a row, it would be more efficient to keep the vehicle in that region than to return to the depot and then return to the region in question.

Additionally, patients may need to be transferred from one specific region to another region (for example, from region 1 to region 2). If there is a large enough number of patients requiring this service, and assuming the depot is not in either of these regions, it would be more efficient to terminate the mission in region 2 than to return to the depot and then go to region 2 the next day.

In order to provide the best service to all patients it is necessary to ensure that a vehicle is assigned to each region at least every few days. The exact number of days is up to the particular user. In the case of the AES, the vehicles must be assigned to the regions at least every three days to ensure patients are picked up within time constraints. Furthermore, due to the regions (other than the depot) having limited facilities, the number of vehicles assigned to terminate their mission away from the depot must be limited. A final constraint is placed on the vehicles. This constraint requires that the vehicle return to the depot after a specific period of time. Returning to the depot periodically helps the maintenance staff keep the vehicles in good running order. The periodic return to the depot is even more important to the AES problem, since the crews are stationed at the depot. Returning home after a period of time aids in keeping aircrew morale high.

Assignment Procedure. Now that the constraints have

been identified, it is possible to assign vehicles to regions in a more efficient manner. The following approach can be used. First, a vehicle is initially assigned to a region if the total patient demand for service exceeds the criteria established by the user. There may be circumstances when the customer demand does not exceed the required amount ($\tilde{a}_{ik}$). In this case a vehicle is not assigned to that particular region; however, the patients for that day are not eliminated. Instead they are added to the next day's patient demand. This is necessary because those patients still require service. It also adds more importance to that region for the next day thus ensuring a vehicle is eventually assigned to that region.

As previously discussed, it may also be necessary to keep the vehicle away from the depot for a day or two. The most efficient method to determine if this is required is to list the values of P_{ijk} (obtained from the patient matrix) in descending order. If a value of P_{ijk} exceeds the minimum requirement for inter-regional service, the vehicle terminates its mission in region j instead of the depot.

It is possible that after the initial assignment of vehicles that some remain unassigned. In this case it could be possible to assign more than one vehicle to service a region. There are two cases that would necessitate the assignment of more than one vehicle.

The first is when the total patient demand for a particular region exceeds the capacity of the vehicle(s). A second vehicle may then be assigned to that region. This is required since it would be impossible to service all patient demands when the demand exceeds the vehicle capacity.

The second case that could occur is somewhat more complicated. If the demand for inter-regional service exceeds the minimum required for two different regions, a second vehicle would then be assigned to that region. This is required because it would be impossible to transport the patients to more than one region if only a single vehicle is assigned. If two vehicles were assigned to the region, each vehicle could transport the patients to the respective regions for an overnight stay.

In assigning the vehicles for overnight stays it is possible that a tie could exist for assigning the vehicles. More specifically, it is possible that two vehicles, from two different regions, have the same number of patients requiring transportation to a particular region. It is also possible that a single vehicle could have the same number of patients requiring transportation to two different regions (as in when the vehicle is in region 1 and has to deliver twelve patients to region 3 and twelve patients to region 4). In these two cases the vehicles are assigned so as to minimize distance traveled. This

approach helps to reduce the time an aircraft must travel.

The following is a list of variables that are used in the heuristic assignment algorithm.

$\tilde{a}_{ik}$ = minimum number of customers in region i requesting service on day k required to assign a vehicle to region i on day k.

β_{ijk} = minimum number of customers requesting service from region i to region j on day k required to terminate mission in region j instead of Scott AFB.

P_{ik} = total number of patients in region i requesting service on day k.

P_{ijk} = number of patients requesting service from region i to region j on day k.

C_{nk} = capacity of vehicle n on day k.

V_k = maximum number of vehicles available on day k.

The first step of the following algorithm is to determine the minimum number of patients required to assign the aircraft to the various regions. This is accomplished by interviewing various individuals with expertise in the AES scheduling process. Since the PAC develops the schedules, they should have a reasonable idea of what range of values are appropriate.

The second step is the initial assignment of aircraft to the various regions on a given day. Any day of the week can be used as this base day -- Monday may be an appropriate choice. If the patient demand exceeds that determined in step one, a vehicle is assigned to that region. This step also ensures that the aircraft does not

have more than four consecutive mission days, thus allowing the maintenance crews to have sufficient time to complete any needed maintenance.

The third step ensures that an aircraft is assigned to the various regions at least every 72 hours. This will allow the schedulers to pick up and deliver all routine patients within the 72 hour time limit.

The fourth step determines if any aircraft should remain away from the depot for more than a single day. If the patient demand is significant the aircraft can RON. It is important to remember that the vehicles must return to Scott AFB at least every three days. This allows any needed (minor) maintenance to be completed as well as allowing the aircrews periods of rest. Additionally, in order to service more patients, the total flight time should not be wasted. Therefore, aircraft should be assigned to the regions in order to minimize total flight time.

Step five allows more than one aircraft to service a region. There are two particular cases when this may be necessary. The final step ensures the procedure is accomplished for all remaining days of the period.

The following is a summary of the heuristic algorithm that is used to provide an initially improved schedule for the AES.

STEP 1. Determine $\tilde{a}_{ik}$ and β_{ijk}.

STEP 2. Let $k = 1$. If $P_{ik} \geq \tilde{a}_{ik}$ for any i, assign vehicle to region i.

If a vehicle has been assigned a mission for four consecutive days, it must have the fifth day off for maintenance purposes.

STEP 3. If $P_{ik} < \tilde{a}_{ik}$, add the patient demand from that region to the next day and do not assign a vehicle.

If a region has not been serviced by a vehicle within 48 hours it must have a vehicle assigned to it regardless of P_{ik}.

STEP 4. Determine maximum P_{ijk} for all i and j. In decreasing order, if $P_{ijk} \geq \beta_{ijk}$, terminate the mission in region j, otherwise return to the depot.

If a vehicle is away from the depot for 72 hours it must return to the depot regardless of P_{ijk}.

STEP 5. If the total number of vehicles assigned for day k is less than V_k, a second vehicle may be assigned if $P_{ik} \geq C_{nk}$ or $P_{ijk} \geq \beta_{ijk}$ for two different j.

STEP 6. Return to STEP 2 and repeat procedure for all k.

This algorithm gives an initial improved schedule based solely on frequency of customer demands. Therefore, any subjectivity of the user should be implemented into the schedule after the initial schedule is developed. There may also be some minor modifications necessary to satisfy the user. The most likely modifications would concern the time constraints in steps two, three and four. Even with these minor adjustments, the algorithm is still applied in the same manner.

Application to AES Scheduling Problem

This section demonstrates how the heuristic algorithm is applied to a real problem. The AES scheduling problem is used in this example. The data used in the analysis is displayed in appendix A. The first step of the algorithm requires values for $\tilde{a}_{ik}$ and β_{ijk} to be determined. Major Paul Lemmings from the Patient Airlift Center believes that using the value of ten for both of these variables is valid. It will at least allow an initial schedule to be determined. Furthermore, no more than six of the available eight aircraft will be scheduled on a given day. This will allow two operational aircraft to remain on standby to service any priority or urgent patients that may be placed into the system.

Monday is arbitrarily chosen to be day one of the scheduling procedure. Examining the data displayed in Table XII shows that four regions have a sufficient number of patients requiring transportation to allow an aircraft to be assigned. Table III displays the schedule after assigning these aircraft. The Xs are used to indicate that it is not presently known from what region the mission originates and terminates. Step two only determines which of the regions should be serviced by the aircraft. Since this is the first day any aircraft are assigned, it is not required to terminate the mission in region six, for any aircraft, so that the aircraft can have the following day

Table III

AES Schedule After Completion of Step 2

Mon	Tue	Wed	Thur	Fri	Sat	Sun
XX1X						
XX2X						
XX5X						
XX6X						
XX3X						

off for maintenance.

Since region four is not serviced, the values from that row are added to the values for region four on Tuesday. This will insure an aircraft services those people who need the service on Monday.

Table XII also shows the inter-regional patient demands for Monday. This is required in order to determine where the mission will terminate. There are no values of P_{ijk} that exceed ten, so all missions are terminated in region six (where the depot is located). Table IV shows what the schedule looks like after this step.

Step five is not necessary on this iteration since there have only been five aircraft scheduled. However, It may be necessary to follow step five in subsequent

Table IV

AES Schedule After Completion of Step 4

Mon	Tue	Wed	Thur	Fri	Sat	Sun
XX16						
XX26						
XX56						
XX66						
XX36						

iterations. Step six requires the first five steps to be repeated for the remaining days of the week to complete the weekly schedule. The remaining iterations are not shown since they are just repetitions of the steps already shown. The initial improved AES schedule, however, is shown in Table V.

While there are several missions that are similar to the current AES weekly schedule (shown in Table I), there are more that differ between the two schedules. The most obvious difference is the schedule for Sunday. The current AES schedule has five aircraft scheduled for Sunday, even though the patient demand does not exceed the previously stated amounts. Furthermore, the current AES schedule has several missions assigned to regions that do not require,

Table V

Initial Improved AES Schedule

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0655	0555	0556		0621
0626	0636		0611	0111	0156	
0656	0655	0566		0622	0226	
	0611	0112	0226	0666		
0666	0663	0336			0646	
0636			0663	0336	0666	
0646	0622	0222	0236		0636	
	0645	0544	0446	0646		

according to the patient demand, an aircraft. Both of these differences could be due to subjective requirements that cannot be evaluated in a model. For example, training requirements may require that the extra missions in the current schedule be flown.

Another important difference between the improved schedule and the current AES schedule is the fact that the patient demand does not justify having any cross-country missions. The current AES schedule has four cross-country missions. This too may be justified, however, by certain AES training requirements. Since the reason for the operation of the AES during peacetime is to maintain readiness for war, it is reasonable that the air crews need to be able to fly cross-country missions.

Furthermore, the improved schedule is merely a foundation. This schedule forms the basis so that any changes that must be made due to training or other subjective requirements can be made after the patient demands are considered.

There are also minor differences in where the missions originate and terminate on subsequent days. This too could be due to subjective requirements. For example, the improved schedule shows a mission 0446 on Thursday and a mission 0646 on Friday. This is due to the requirement to return to the depot after 72 hours. If the 72 hour time constraint is relaxed, the aircraft could stay in region four for another day and thus reduce the time it takes to travel to and from the regions.

A final, and quite obvious, difference occurs during the application of the algorithm. The final improved schedule for Monday is different than the schedule produced after step two of the algorithm. Initially, there is no mission to region four on Monday since there is insufficient patient demand. However, there is also not a need for a mission to region four on Sunday. This is the last day of the schedule, but it must still be connected to the missions on day one. After adding the patient demand from Sunday to Monday, there is a sufficient number of patients to assign an aircraft to region four on Monday.

Therefore, as previously stated, Table V displays an

initial improved schedule for the AES. This is likely not the best schedule available; it improves the current AES schedule using the patient demands as a basis. Further adjustment may be necessary to incorporate additional requirements, such as training missions.

Sensitivity Analysis

The previous section developed an initial improved schedule that could be used by the AES. However, it is still not determined how sensitive that schedule is to changes. For example, it is important to determine if the schedule that has been developed is still an improvement if the values of $\tilde{a}_{ik}$ and β_{ijk} increase or decrease. It is also important to determine if the schedule is an improvement throughout the year. The data that is used to improve the schedule is the average patient demand, for the year, on any given day. This may be seasonal in nature: i.e., change from summer to winter or from spring to fall. This section examines the schedules that are developed after making these changes and compares them to the initial improved schedule.

Sensitivity to $\tilde{a}_{ik}$ and β_{ijk}. The values of $\tilde{a}_{ik}$ and β_{ijk} were initially set to ten. This section follows the same algorithm as before, with the exception that $\tilde{a}_{ik}$ and β_{ijk} are set first to fifteen and then to five.

With these parameters set to fifteen, the algorithm is applied to the data in appendix A (average patient

demand for a year), and the schedule in Table VI is obtained.

Table VI

Initial Improved AES Schedule

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0656	0655	0556		0621
	0636		0616	0611	0156	
0656	0655	0566		0622	0226	
	0611	0116	0626	0666		
0666	0663	0336				
			0663	0336		
	0622	0226	0636		0633	0346
	0646	0644	0446	0646		

This is basically the same schedule that is obtained when the parameters are set to ten. The main difference in the two schedules is that there are fewer missions flown when $\tilde{a}_{ik}$ and β_{ijk} are equal to fifteen than when they are set to ten. This is expected since it takes more patients in a particular region to assign an aircraft to that region. The other minor difference in the two schedules is the region in which the aircraft terminate their mission. This is due to not having sufficient patients to require the aircraft to stay away from the depot for the night.

Even with the differences, one factor is obvious:

The initial improved schedule that is obtained in the previous section is still valid when $\tilde{a}_{ik}$ and β_{ijk} are increased from the nominal value of ten. More missions may be flown than are needed, but all the regions that require service still have aircraft assigned.

The same conclusion is drawn when $\tilde{a}_{ik}$ and β_{ijk} are reduced to five. Since the assignment of aircraft is limited to six aircraft and the missions are restricted to four days, basically the same schedule is obtained when the parameters are reduced to five. The only difference is that there are two more aircraft assigned to Sunday when the parameters are set to five than when they are set to ten. Therefore the same schedule could be obtained by subjectively assigning those two missions to the initial improved schedule previously obtained.

Sensitivity to the Seasons. This section examines the data presented in appendices B, C, D and E. This data is the same as the data in appendix A, except that it is broken down into the four seasons and then averaged for the days of the week, thus corresponding to spring, summer, fall and winter, in appendices B, C, D and E, respectively. The results of this analysis are shown in Tables VII, VIII, IX and X.

These tables show that the original improved schedule developed for the AES, using the aggregated yearly data, is appropriate for use throughout the year. There are a

Table VII

Initial Improved AES Schedule for Spring

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0656	0655	0556		0621
0626	0636		0611	0111	0156	
0656	0655	0566		0622	0226	
	0611	0112	0226	0666		
0666	0663	0336				
0636			0663	0336	0666	
0646	0622	0222	0236		0636	
	0645	0544	0446	0646		

Table VIII

Initial Improved AES Schedule for Summer

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0655	0555	0556		0621
0626	0636		0616	0611	0156	
0656	0655	0566		0622	0226	
	0611	0112	0226	0666		
0666	0663	0336			0646	
0636			0663	0336	0666	
	0622	0222	0236		0633	0346
	0645	0544	0446	0646		

Table IX

Initial Improved AES Schedule for Fall

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0655	0555	0556		0621
0626	0636		0616	0611	0156	
0656	0655	0566		0622	0226	
	0611	0112	0226	0666		0616
0666	0663	0336			0646	
			0663	0336	0666	
0646	0622	0222	0236		0636	
	0645	0544	0446	0646		

Table X

Initial Improved AES Schedule for Winter

Mon	Tue	Wed	Thur	Fri	Sat	Sun
0116		0655	0555	0556		0621
0626	0636		0611	0111	0156	
0656	0655	0566		0622	0226	
	0611	0112	0226	0666		
0666	0663	0336				0646
0636			0663	0336	0666	
	0622	0222	0236		0636	
	0645	0544	0446	0646		

few differences between the schedules, but in most cases the original improved schedule has as many missions or more than the schedules for each of the four seasons. Furthermore, the total number of missions to each region is approximately the same for all schedules. This is an important point since it is not uncommon for systems that have dynamic demands to fluctuate throughout the year. Therefore, the original improved schedule is appropriate for use the entire year.

The various types of sensitivity analysis that have been examined in this section show that the original improved schedule developed using the yearly data is valid for a wide range of $\tilde{a}_{ik}$ and β_{ijk} values as well as the various seasons of the year. The few differences that did occur could be justified the subjectivity and requirements of the user.

Summary

This chapter reviewed the few articles that have been written about the assignment, fixed and periodic routing problems. These works were used to form the foundation for developing a heuristic algorithm that can be applied to the AES, or to other systems in which vehicles are assigned according to customer demands, to develop an initial improved weekly schedule for the AES.

In order to demonstrate the validity of the algorithm, it was applied to the AES to develop the aforementioned

schedule. The data used in this algorithm is obtained from the Patient Airlift Center at the AES and is displayed in appendices A, B, C, D and E. The data is in matrix form to facilitate the application of the algorithm. Examining the data shows that there are definitely patient demand patterns that need to be addressed.

Finally, a sensitivity analysis is performed on the schedule that is developed. Changes to the patient demand necessary to assign an aircraft are examined, as well as the effects of seasonality. Throughout the sensitivity analysis the original improved schedule proved to be effective. A final consideration that should be reviewed is the impact of the AES schedule on patient demand. For example, does the patient demand increase on certain days simply because the AES has an aircraft scheduled for that day? This question is examined further in Chapter V.

IV. The Daily Routing Problem

Introduction

The previous chapter developed an algorithm for improving a fixed weekly schedule for an aeromedical transportation system. In particular, the AES was chosen for the example. Even though it is important to develop an improved schedule that is to be used for routing, the fixed schedule is only the initial problem. In order to complete the process, the daily routing problem must also be examined.

The daily routing problem changes every day. Patient demand patterns are dynamic and therefore the daily routing problem becomes even more difficult to solve. However, by using the fixed weekly schedule as a basis and developing an appropriate algorithm, the daily routing problem can also be more efficiently solved.

The AES requires N entities (aircraft) to travel to M different locations. The aircraft originate at the main node (Scott Air Force Base) and travel to various airfields, visiting each airfield at least once, and then finish the tour at the origin. Additionally, each patient must be picked up at their specific origin before being delivered to their destination. The traveling salesman problem, as originally posed in 1934 by Whitney (6:62), requires a "salesman" to visit N cities exactly once and

return to the origin at the least cost. Although this simple model will not accurately portray the true AES, it will give a solid basis for additional modifications. This model is appropriate when it is assumed there is only one aircraft transporting patients through the system. Additionally, it has been shown that multiple traveling salesmen (aircraft) problems are simple extensions of the original case (14:347).

The AES has a fixed number of aircraft, so the multiple traveling salesmen problem more accurately models the system. The multiple traveling salesmen problem has M salesmen and N cities to be visited. Each city, except the origin, must be visited by only one "salesman" (14:347). Additionally, only one salesman is to be assigned to each tour (7:455). Clearly, these two problems are related; therefore, a technique that provides a feasible solution to the multiple traveling salesman problem would also be expected to provide the optimal routes for the AES.

Three more considerations dealing with this problem must be reviewed. First, the multiple depot aspect is required with the AES. The current schedule shows that all aircraft do not originate from the same depot every day. Therefore, this modification must be implemented. The multi-depot routing problem requires the following assumptions:

1. one aircraft is assigned to each of the M depots.
2. Each aircraft must be used, and it must start and end its route at its assigned depot.
3. a route cannot visit more than one depot.

(14:355)

The second consideration that must be examined is precedence. Obviously the patients must be picked up at their origins before they can be delivered to their destinations. This requires that the patient's origin has precedence over the destination. For example, the optimal route (minimum distance) may be determined to be Origin -> A --> B --> C --> D --> E --> Origin as in Figure 2. However, a patient at node D may require treatment at node A and a patient at node E may require treatment at node D, therefore this routing would be infeasible (node E must be visited before node D just as node D must be visited before node A as in Figure 3).

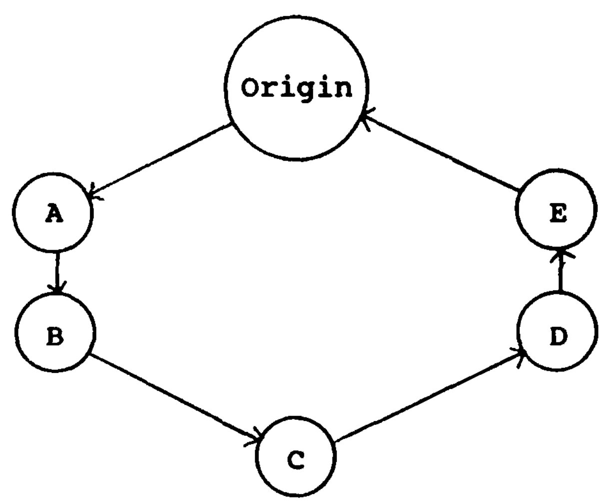

Figure 2. Optimal Routing without Precedence

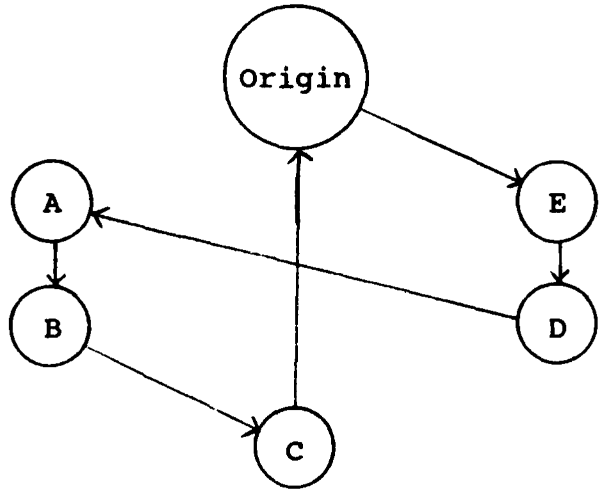

Figure 3. Optimal Routing with Precedence

Finally, the impact of multi-period scheduling should be examined. With the exception of urgent patients, patients in the system do not necessarily have to be delivered to their destination the same day. It would be desirable, especially for the patients, if they could be picked up and delivered in the same day, but restrictions on the number of stops allowed as well as the length of the crew's duty day make it impossible to deliver all patients to their destination in one day. Therefore, the problem must be modified so that, as the current schedule shows, the routes cycle throughout the week.

Furthermore, the multi-period scheduling problem must consider the effects of maintenance and patient transfers between regions. Scott Air Force Base is the central base for aircraft maintenance and crew basing (14:388). It is necessary, therefore, that the aircraft cycle through that

base. McLain states that an unwritten rule is once every one to two days the aircraft should cycle through the central base (14:388). The second multi-period scheduling problem is the effect of patient transfers between regions. Patients normally receive treatment at the nearest medical facility that can provide the treatment. However, patients can be transported to a medical center further away if they have a physician preference or if it is nearer to their place of residence (1:25).

There are numerous sources in the literature that give various model formulations for this type of routing problem. The following section gives only a few of those sources as they would apply to the AES routing problem.

Literature Review

The traveling salesman problem can also be thought of as a routing problem. Any problem in which it is important to obtain the optimal delivery route for a specific type of vehicle is called a vehicle routing problem. All destinations may be visited only once, with the exception of the originating depot (12:1050). Therefore, the primary difference between the traveling salesman problem and the vehicle routing problem is that one deals with people and the other deals with vehicles. In fact, most vehicle routing problems are extensions and variations of the traveling salesman problem (8:115).

The algorithm introduced by Laporte, Nobert and

Desrochers (12:1057) describes the concept of branching when constraints are applied to the problem. A few of the possible constraints that could be imposed are:

1. the depots (number, locations).
2. the vehicle fleet (types, numbers, capacities).
3. the number of destinations.
4. the routing structure (precedence).
5. system dynamics (patient demand).

(8:113-114)

In relation to the AES problem, branching is a feasible methodology to solve the daily routing problem. The problem is first solved by assuming there are no constraints, such as aircraft capacity and aircraft range. If the solution that is obtained violates any of the constraints, then a restriction is applied on the specific variable that violated the constraint and the problem is re-solved. This is a slow procedure since it may require many iterations. However, it does generate a feasible solution and is much better than a complete enumeration of all possible solutions.

Current, ReVelle and Cohon expanded the vehicle routing problem solution to include the multi-objective case. Vehicle routing problems are multi-objective in nature due to the way they are constructed (4:189). This is due to the fact that the objective is to maximize the amount of cargo transported and at the same time minimize the total distance traveled, total travel time and total number of vehicles used. Therefore, it is not realistic

to optimize the AES problem, or any vehicle routing problem, with respect to only one objective. The final solution must take into consideration several interrelated objectives such as patient requirements, time, cost and distance. Additionally, Current explains that public transportation problems are already using the multi-objective criteria in obtaining optimal schedules (4:198).

The algorithm that Current introduces relates two important objectives: maximum coverage and shortest path (4:189). Again, this is fundamental to the aeromedical evacuation system. This feature alone will allow the system to reach more patients in less time. The model formulation requires introducing a second objective function to the original problem. Furthermore, constraints are added to relate and connect the two objective functions (4:191).

As quoted by Current, Steenbrick claimed that "it is impossible to define a reasonable objective function for the transport network optimization problem in which all relevant factors are included completely and consistently" (4:198). This difficulty is indeed always present. However, by using the multi-objective models, the analysis of more criteria than allowed by the original optimization methods can be achieved (4:198).

Skitt and Levary also introduce variations to the ordinary vehicle routing problems. Although not yet

complete, their algorithms add two important features. First, the entity (aircraft) is allowed to have its own specific origin and destination. It is not necessary to have all entities originate at the same node (16:67). Secondly, locations may now be visited more than once. If these two aspects are required, most ordinary algorithms could not be used (16:67). This is important to the AES routing because more populated regions often require an aircraft to stay in that region and visit the same airfield frequently (1:152).

The two new aspects previously mentioned, multi-depot and repetitive visits, inherently create a problem when trying to obtain a solution. The number of possible solutions will increase due to the additional flexibility introduced. Therefore, Skitt and Levary introduce the idea of column generation. If K is the number of possible solutions, then a subset of K is used to determine the optimal solution of the sub-problem. If no feasible solution can be found, a new column of possible solutions is generated and the process is repeated until the optimal solution is obtained (16:68).

The article by Kalantari, Hill and Arora uses a similar procedure to that of Laporte, Nobert and Desrochers. A branch and bound algorithm is used to expand the traveling salesman problem to one which has specific pick-up and delivery customers. That is, the pick-up

customer must be visited before its corresponding delivery customer is visited (11:377). This makes the algorithm especially applicable to the AES. The patients (pick-up customers) must be visited prior to delivery to the corresponding regional hospital (delivery customers).

The branch and bound algorithm divides all possible solutions (routes) into smaller subsets using an iterative procedure. Moreover, each subset is bounded by the constraints. An optimal solution is reached once a feasible subset is found that is optimized when compared to all other bound subsets (11:379).

This method has also been generalized to the case where there are M salesmen. As in other algorithms, the solution is obtained by a series of substitutions that reduce the problem from M salesmen to the one salesman case (11:379). These substitutions are obtained by creating M duplicates of the origin and of the connections from the origin to the other nodes. The duplicate origins are not connected (8:117). The M sub-problems are then solved for the optimal routes.

Held, Hoffman, Johnson and Wolfe examined several algorithms that have been applied to the traveling salesman problem. The general linear programming problem has often been used in solving the traveling salesman problem (9:478). An advantage of linear programming is that it can handle the problem of permutations very well. That

is, if there are N different people and N jobs that need to be done, then there are numerous ways to assign each person (aircraft) to the different activities (routes) and still complete all jobs (9:479). This is applicable to the AES because it is possible to take several different routes with each of the various aircraft. The problem is to assign the aircraft to the different routes so as to optimize the objective function. The objective function may be with respect to the maximum customers per mile, minimum turn-around time or a combination of other possible objectives. This can be related to the algorithm introduced by Current, Revelle and Cohon dealing with multiple objectives.

Another methodology that has been applied to the traveling salesman problem is integer programming. Integer programming is formulated similar to linear programming with the exception that the solution must contain integer values. Additionally, any pure integer program with multiple constraints can be reduced to an integer program with a single constraint (i.e. the knapsack problem) (9:481). Again, this is applicable to the AES in that the solution must, at least partially, contain integer solutions. It would not be feasible to assign half of an aircraft to a route.

Enumeration and branching has been incorporated into several methodologies already examined. It is a difficult

task to completely enumerate all possible solutions for any problem of appreciable size. However, all solution techniques for the traveling salesman problem, as well as other problems, involve some degree of enumeration. The main difference in the techniques is how they reduce the amount of enumeration (9:482).

Branch and bound is the technique that many software packages use to reduce the amount of enumeration (9:482). Branch and bound algorithms have three parts. First, the main problem is divided into sub-problems. The sub-problems are then optimized (branching). Bounding occurs when some of the sub-problems are eliminated (9:482). This, in turn, reduces the computational effort that would be required.

Christofides and Beasley (3:237) developed two heuristic algorithms to solve the multi-period routing problem. Periodic routing problems require routes to be determined for each day of a given k-day period. The first procedure requires solving several (zero-one) sub-problems. This problem generates a large number of variables and therefore is not tractable except for trivial problems.

A second method that could be used to solve the problem is to relax the vehicle routing problem constraints for each day of the period. The resulting sub-problems are similar to the original vehicle routing problem. These sub-problems are simply traveling salesman problems

(3:240). Each sub-problem is solved for an optimal solution. If the optimal solution to the sub-problem is also feasible for the original problem, it remains in the solution space. If the optimal solution is infeasible for the original problem, it is discarded; however, it is possible that slight constraint violations may still be considered feasible. The constraints are developed by determining maximum customer demand for each period. Therefore, any solution obtained that is based on these constraints would be feasible for all periods. This would make the routes under-utilized since the routes would only be at maximum capacity on a few days. These types of algorithms appear promising since the AES problem depends on being repetitive over several periods.

Lev and Kwatny (13:36) have developed an interactive computer program to plan a corporation's meeting schedule. The program inputs include origins, destinations, travelers and travel times. The algorithm used in the program is not analytical, as in the previously described techniques. Instead, it uses simulation to determine the optimal solutions. "Solutions" is the correct word here because this simulation program does not give one single schedule. Rather, several solutions are derived and then it is the responsibility of the decision maker to choose the schedule that is preferred (13:36). This allows the subjectivity of the decision maker to determine the "best" schedule.

This information would seem to exclude the computer model by Lev and Kwatny from being a feasible alternative for the AES. However, this type of simulation is necessary when dealing with another facet of the problem. The effect of changes to the schedule (due to priority or urgent patients) could easily be determined by using this simulation. It would be impossible to determine this effect using purely analytical methods without re-solving the problem for each change.

McLain (14:246) developed several models to simulate a type of traveling salesman problem. His algorithms were directly related to the AES. He did not however, develop the specific code to solve the problem of finding the optimal route. This was mainly due to the limitations of algorithms for solving the multi-period routing problem.

McLain employed two techniques already discussed to solve some variations of the AES routing problem. First, it was determined that integer linear programming could be used to solve the problem. However, due to the limitations of available integer linear programming algorithms, a branch and bound approach was incorporated to aid in solving the integer linear program (14:10). Therefore, as previously mentioned, several approaches may be required in order to obtain an optimal solution.

Model Development

The following model is formulated for the single

vehicle case. This formulation is valid for the AES since the majority of the time a single aircraft is assigned to service a particular region. The multi-vehicle formulation is similar and can be found in numerous sources. There are basically two major components that need to be formulated. The first consideration is the objective function. The objective function measures the effect of the consequences of a decision. The second consideration deals with the constraints. The constraints are functions (either equalities or inequalities) that restrict the range of the decisions. The class of problems that involve routing are easily formulated as 0-1 integer programming problems. The following formulation is based on minimizing the total distance traveled, as per the traveling salesman problem.

The first step in formulating the problem is to determine the decision variables. The decision variables take on certain values with each corresponding decision. The decision variables that are used in this formulation are x_{ijk} where

$$x_{ijk} = \begin{cases} 1 & \text{if the routing includes an arc from node } i \text{ to node } j \text{ on leg } k \text{ of the routing.} \\ 0 & \text{otherwise.} \end{cases}$$

The following quantities are also used in the model formulation:

D = final destination node of the trip
I = total number of emanating nodes
J = total number of terminating nodes

K = total number of legs on trip

Objective Function. Since the main concern (objective) is to minimize the total distance traveled, the objective function is developed to measure how the various decisions impact the total distance traveled. The objective function

$$Z = \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} d_{ijk} x_{ijk} \qquad \text{for } i \neq j \qquad (1)$$

describes the total distance traveled. The variable d_{ijk} is the distance from node i to node j on the k^{th} leg of the route. Since it is not desirable to travel from node j to node j on a leg (the same as staying at a single node and losing a trip leg), the values of d_{jjk} for all k are set to . By summing all the arcs traveled ($x_{ijk} = 1$), the total distance traveled can be determined. The constraints are now formulated to determine which decisions are feasible.

Constraints. Obviously, the trip must begin at the origin. Therefore, a constraint must be provided to restrict the first leg of the route to originate from the origin. Since only one arc is allowed from the origin to all other nodes on leg 1, the following holds.

$$\sum_{j=2}^{J} x_{1j1} = 1 \qquad (2)$$

Furthermore, the trip must terminate at the final destination. This requires one arc to enter the final node on the last leg of the trip. However, if the total number of legs is not known, further restrictions must be placed on the trip legs. The constraints

$$\sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} \leq K_{upper} \qquad (3)$$

$$\sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} \geq K_{lower} \qquad (4)$$

restrict the total number of arcs that can be traveled on a trip. The AES requires that no more than eight stops be made on a mission. Constraints (3) and (4), relating to the maximum and minimum number of arcs respectively, could also be modeled as equalities. That would require exactly K legs be taken, no more and no less.

Since the number of arcs that can be traveled is now restricted, the following constraint requires the trip to end at the terminal node.

$$\sum_{i=1}^{I} x_{iDK} = 1 \qquad (5)$$

Each stage of the routing can only be associated with a single arc. That is, only one trip can be taken during each stage.

$$\sum_{i=1}^{I} \sum_{j=2}^{J} x_{ijk} = 1 \quad \text{for } k = 2,\ldots,K-1 \tag{6}$$

This constraint is only required for the legs after the initial leg and before the final leg since those two legs are restricted by previous constraints.

Normally there are two constraints that require each node to be visited only once. However, the total number of legs have been restricted so it may not be possible to visit all nodes. For this reason, the following constraints guarantee that there is no more than one departure from each node and no more than one arrival at each node. The originating and terminating nodes are exceptions since they must have exactly one departure and one arrival, respectively.

$$\sum_{j=2}^{J} \sum_{k=2}^{K} x_{ijk} \leq 1 \quad \text{for } i = 2,\ldots,I \tag{7}$$

If $j = D$, $k = K$

$$\sum_{i=1}^{I} \sum_{k=1}^{K-1} x_{ijk} \leq 1 \quad \text{for } j = 2,\ldots,J \tag{8}$$

If $i = 1$, $k = 1$

Since these constraints do not require each node to be visited, constraint (4) becomes even more important. Constraint (4) forces the vehicles to make at least K_{lower} stops. This will insure the program does not produce an

optimum route going from the origin directly to the destination.

There exists the possibility that disjoint tours may occur instead of a single continuous tour. For example, if there are five nodes to be visited, the desired single tour may be 1 --> 2 --> 3 --> 4 --> 5. However, disjoint tours could create two sets of tours. The constraints must be developed to ensure that if a trip terminates at node j on a leg, it must begin the next leg at node j. The first constraint ensures there is continuity for the first leg.

$$x_{1j1} = \sum_{t=2}^{J} x_{jt2} \quad \text{for } j = 2,\ldots,J \tag{9}$$

The next constraint guarantees continuity for all intermediate legs of the tour.

$$\sum_{i=2}^{I} x_{ijk} = \sum_{t=2}^{J} x_{jtk+1} \quad \text{for } j = 2,\ldots,J; \; k = 2,\ldots,K-2 \tag{10}$$

The final constraint to guard against disjoint tours ensures continuity on the final leg of the tour.

$$\sum_{t=2}^{I} x_{tjk-1} = x_{jDK} \quad \text{for } j = 2,\ldots,J \tag{11}$$

This is the complete model formulation for most vehicle routing problems. However, this formulation is

intended to be used by the AES, and therefore, two more constraints have to be developed. The first constraint concerns the amount of time a mission can last. Obviously, for safety reasons, there is a maximum amount of time an aircrew can be allowed to fly. Also, there is a minimum duration for the mission, for training purposes. For these reasons a constraint must be formulated to ensure the mission is efficiently and safely planned.

$$\sum_{i=1}^{I} t_i \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} + \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} t_{ijk} x_{ijk} \leq T_{upper} \quad (12)$$

$$\sum_{i=1}^{I} t_i \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} + \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} t_{ijk} x_{ijk} \geq T_{lower} \quad (13)$$

The value of t_i is the time required on the ground at each node i while t_{ijk} is the time it takes to travel between node i and node j during leg k. This formulation allows the time on ground to vary at each node. This occurs in actual routing because the vehicle may have to pick up more passengers at one node than another. Therefore, the vehicle has to remain at the node longer. T_{upper} is the maximum amount of time a mission is allowed to proceed. In the AES example it is sixteen hours. T_{lower} is the desired minimum duration of the mission. This constraint serves a similar purpose to constraint (4) in that it forces the trip to be at least T_{lower} in duration.

The last set of constraints is common to all pick-up

and delivery problems since it ensures the precedence relationships. A patient has to be picked up at his origin before he can be delivered to his destination. This set of constraints ensures that the precedence relationships hold.

There are two methods that can be used to develop the precedence constraints. The first method is enumerate all possible paths and apply a branch and bound technique on the tour set to determine the optimal path (14:312). This method could become very cumbersome since the total number of possible paths are K!, where K is the number of trip legs. For instance, the AES routing problem is restricted to eight legs. This requires 8! (40,320) possible routes to be included in the initial tour set.

The set of possible tours is reduced, however, by eliminating all infeasible routes. A route is considered infeasible if it requires a patient's destination node to be visited before the patient is picked up (14:315). A route is also infeasible if it violates the time constraints for the vehicle.

The VRP that has been formulated is finally solved restricting the solution space to consist only of the feasible routes. A branch and bound technique is also applied to determine the optimal path. Obviously this is not the most efficient method that can be used to solve the AES routing problem.

The second approach is to formulate a new set of constraints similar to those already developed. The formulation is similar in that the decision variable x_{ij} is used instead of x_{ijk}. The primary difference in the two formulations is that using x_{ijk} will require more variables to be defined.

McLain examines a method formulated by Gavish and Srikanth. The formulation is a mixed integer program; that is, not all variables are restricted to be integer. This method is more efficient than that of enumeration but it is also more restrictive due to assumptions made in the formulation.

The following assumptions must hold for the formulation of the precedence constraints as presented by Gavish and Srikanth.

1. each node (except the depot) is exclusively either an origin or a destination for one and only one passenger.
2. the depot is neither an origin nor a destination for any passenger.
3. there are n passengers, and hence 2n + 1 nodes.

(14:310)

The first constraint forces the flow in successive arcs, along the solution path, to increase in unit increments.

$$\sum_{j=2}^{J} y_{ij} - \sum_{j=2}^{J} y_{ji} = 1 \qquad \text{for } i = 1,\ldots,I \qquad (14)$$

(14:311)

The decision variable y_{ij} is not required to be integer.

The following constraint forces the flow out of the passenger's destination to exceed the flow out of the passenger's origin by at least one unit. This ensures that the destination node must be at least one node after the originating node (14:313).

$$\sum_{j=2}^{J} y_{n+ij} - \sum_{j=2}^{J} y_{ij} = 1 \qquad \text{for } i = 1,\ldots,I \qquad (15)$$

(14:311)

This formulation requires $2(n^2 - 2n)$ variables and $4n^2 + 8n + 3$ constraints (14:314). Therefore, assuming the AES has only four patients at four separate nodes and they require transportation to four different nodes (none of which is the depot), this formulation requires sixteen variables and 99 constraints. Any additional patients, and thus additional nodes, would continue to increase these numbers.

Therefore, the second formulation, although not trivial, is much more efficient than that of enumeration. The formulation is very restrictive however. It is not likely that the AES will have n patients at n different source airfields that require transportation to n different destination airfields. Instead, the AES moves patients for several of the smaller medical facilities to the few larger medical centers (14:155). For example, fifteen hospitals accounted for 82.84% of all patient destinations

in 1978; however, these same hospitals only accounted for 47.97% of all patient origins (14:157-8).

It is obvious that the assumptions made in order to formulate constraints (14) and (15) do not hold most of the time. Although this does not mean that the constraints never hold.

Two methods to ensure precedence have been examined. The first is very inefficient and the second is very restrictive. For these reasons, researchers are looking to heuristics to formulate an algorithm to obtain a good, quick feasible solution (14:325). Additionally, the algorithm must be sufficiently general so as to be applicable to a wide range of problems.

One final consideration must be examined. The capacity of each aircraft (C-9) in the AES inventory is forty patients. The schedulers must ensure that this capacity is not violated throughout the mission. This is simple enough since, on most days, the total patient demand for each region does not exceed the aircraft capacity.

The following then summarizes the zero-one integer formulation for the daily routing problem as could be applied to the AES. The formulation includes the objective function to be minimized as well as the thirteen constraints previously mentioned. This formulation is for the single vehicle problem; however, minor adjustments would make it valid for the multi-vehicle problem as well.

$$\text{Minimize } Z = \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} d_{ijk}x_{ijk} \quad \text{for } i \neq j \tag{1}$$

subject to:

$$\sum_{j=2}^{J} x_{1j1} = 1 \tag{2}$$

$$\sum_{i=1}^{I} x_{iDK} = 1 \tag{5}$$

$$\sum_{i=1}^{I} \sum_{j=2}^{J} x_{ijk} = 1 \quad \text{for } k = 2,\ldots,K-1 \tag{6}$$

$$\sum_{j=2}^{J} \sum_{k=2}^{K} x_{ijk} \leq 1 \quad \text{for } i = 2,\ldots,I \tag{7}$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K-1} x_{ijk} \leq 1 \quad \text{for } j = 2,\ldots,J \tag{8}$$

$$x_{1j1} = \sum_{t=2}^{J} x_{jt2} \quad \text{for } j = 2,\ldots,J \tag{9}$$

$$\sum_{i=2}^{I} x_{ijk} = \sum_{t=2}^{J} x_{jtk+1} \quad \text{for } j = 2,\ldots,J; \; k = 2,\ldots,K-2 \tag{10}$$

$$\sum_{t=2}^{I} x_{tjk-1} = x_{jDK} \quad \text{for } j = 2,\ldots,J \tag{11}$$

$$\sum_{i=1}^{I} t_i \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} + \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} t_{ijk}x_{ijk} \leq T_{upper} \tag{12}$$

$$\sum_{i=1}^{I} t_i \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} + \sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} t_{ijk}x_{ijk} \geq T_{lower} \tag{13}$$

$$\sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} \leq K_{upper} \tag{3}$$

$$\sum_{i=1}^{I} \sum_{j=2}^{J} \sum_{k=1}^{K} x_{ijk} \geq K_{lower} \tag{4}$$

$$\text{where } x_{ijk} = \begin{cases} 1 & \text{if the routing includes an arc from node } i \text{ to node } j \text{ on leg } k \text{ of the routing.} \\ 0 & \text{otherwise.} \end{cases}$$

$i = 1,\ldots,I$

$j = 2,\ldots,J$

$k = 1,\ldots,K$

Additionally, some method must be used to ensure precedence relationships along the tour are maintained. These methods may be similar to the two discussed in this section, a purely heuristic approach, or a combination of all three.

Solution Techniques

There are two solution techniques for this type of problem that are widely publicized. The first solution technique is a cutting-plane approach. This approach initially relaxes the integer requirement and solves the resulting linear program. If the solution results in the required integer variables, the procedure is terminated. However, if any of the integer variables are violated, the following modifications are introduced.

The modification to the original model is the addition of a constraint, representing the cutting plane. This cutting plane eliminates some of the non-integer solutions, but does not remove any of the feasible integer solutions.

The branch-and-bound method is the second approach that can be used to solve the AES routing model. The branch-and-bound method is an extension of various implicit enumeration techniques. It is important to realize that implicit enumeration is not necessarily the same as complete enumeration. In the 0-1 integer program for the AES formulation there could be 2^{448} possible solutions since there could be 448 variables. This would require an

excessive amount of computation.

The branching approach is accomplished by adding two new constraints to the problem. These restrictions are placed on any variable that is non-integer but required to be integer. The problem is then solved with these additional constraints. The problem is then bounded when the solution produced is infeasible, or no better than the previous best solution. The process is continued until an optimal solution is obtained.

Summary

This chapter reviewed the literature that is available for formulating and solving problems similar to the traveling salesman and vehicle routing problems. This study formed the foundation for developing a model that may be used to solve the AES daily routing problem.

An integer programming model is then formulated that could be used to solve this problem. The objective function and constraints are then defined.

Finally, a few of the possible solution techniques are reviewed. Additionally, the application of these techniques to the AES daily routing problem is discussed. This discussion includes how large and fast the constraints, variables and solution space can grow for problems with only a few nodes.

V. Summary, Conclusions and Recommendations

Conclusion

This thesis examines several methods that may be used to solve the scheduling and routing problems of the AES. Additionally, the background of the problem was reviewed as well as the scope of the solution to be presented. The fundamental knowledge of the AES mission, goals and expectations allows a more accurate algorithm to be formulated. The algorithm is more accurate because it portrays the AES more realistically.

There has been a great deal of research done in the area of routing problems, scheduling problems, multi-period problems, and precedence problems. However, as the literature review has shown, no one algorithm exists to solve combinations of these problems. More specifically, the AES has not even formalized the methodology they use to determine the weekly schedules. This makes the final output of this thesis, a formal algorithm to improve the fixed weekly schedule, even more valuable. The heuristic algorithm presented herein formalizes the weekly scheduling process of the AES.

Application of this algorithm produced an initial improved schedule. This schedule reflects the patient demand. Additionally, this schedule is similar to the current AES schedule in many aspects. There are, however,

several differences between the two schedules. These differences may be justified by various subjective and training requirements.

There is also a sensitivity analysis performed on the improved schedule. The schedule changed very little by changing patient demand requirements and by examining the data on a seasonal basis instead of annualy. This is an important fact, since it is necessary to know if the improved schedule is valid only for the available data or for a range of values. It is possible, due to the dynamic nature of patient demands, that the improved schedule is valid for the annual data, but infeasible for one or more of the seasonal data.

One final aspect that must be examined further is the effect of the schedule on the patient demand. If the physicians know that the AES has an aircraft scheduled for a given region on a given day, they are more likely to request service on those days instead of when it is initially required. In other words the schedule may dictate the demand rather than the demand dictating the schedule. This is particularly true for routine patients where time is not as high a priority. This fact alone would tend to make the current schedule in use look as though it is better than others.

After the improved weekly schedule is developed and implemented, the second, and more difficult, AES problem

is examined -- the daily routing aspect of the AES. Since the AES daily routing problem is similar in nature to the traveling salesman problem, only the algorithms that have been used to solve traveling salesman type problems are reviewed. Assumptions that could impact the scope of the problem are also examined.

The literature review shows there is not a "single" method that can be used to solve the traveling salesman problem. This is because the algorithms were designed for problems with specific characteristics. Therefore, several algorithms must be reviewed and applied to solve any generalized traveling salesman problem. The AES, which is a generalization of the traveling salesman problem, therefore requires various algorithms to ensure an optimal solution.

The importance of formulating these various algorithms cannot be over emphasized. The AES is an organization that deals with saving lives. It is obviously one of the most important organizations not only in the military services, but in the United States. Therefore, the AES routing and scheduling problem is a very important topic to be researched and analyzed because not only will this save time and money, but it could save lives as well.

Recommendations

The results of this thesis indicate that the importance of a fixed weekly schedule should be lessened.

At most there should be a flexible weekly schedule. This type of schedule should be capable of changes due to patient demands or user requirements. Also, the effects of the different seasons or even the different months should be considered when developing the schedules.

It would also be valuable to run some type of simulation on the improved schedule. This simulation should randomly input all categories of patients to the AES. The actual savings, by using the improved schedule could then be calculated.

However, the greatest emphasis should be placed on the AES daily routing problem. The difference in the literature review for the two types of problems already indicates more research is being done in the area of daily routing than in fixed or assignment routing. The optimal solution may have the best of both problems -- an interaction between a flexible weekly schedule and the daily routing. The most obvious method of accomplishing this would be to develop an interactive system to handle this difficult task.

The AES is currently considering implementation of a system called the Automated Patient Evacuation System (APES) (5:9). This system will provide communication links between AES units. Furthermore, APES will be capable of

1. generating proposed mission plans.
2. notifying origin/destination medical facilities.
3. generating summary reports.

4. quality control for urgent/priority patient movement.

(5:10)

Another area which should be examined in more detail is the process in which service is requested. Most medical regions have at least one large medical facility. There does not seem to be a need to have a significant percentage of the patients travel outside of these medical regions. The main objective is to provide the patients with the necessary medical treatment at the "closest" medical facility. Even though the patients may request another facility, except in extreme situations, they should be assigned to the one nearest to them. This would simplify the daily routing of patients and would also reduce the number of RONs the patients would have to endure. Obviously this is not going to be possible all the time. There will be instances in which a patient needs a service that is supplied at only a few medical facilities. However, this type of patient movement could definitely be reduced, resulting in improved patient care.

Research Extensions

There are several areas in which further research is worthwhile to pursue. The development of a software package that could interface with APES is needed. This software package should be able to work interactively with the schedulers. It will require both work in the flexible routing and daily routing.

Additional research efforts in the area of software development to incorporate the flexible weekly scheduling of aircraft is needed. The flexible routing aspect will allow the computer to automatically change the assignment of aircraft when changes in the patient demands outside of predetermined limits is noticed. This will eliminate the need for the AES to evaluate the data by hand every six months in order to change the schedule. It will also be more efficient in that changes in the schedule will be made as soon as the demand change is noticed.

The emphasis, however, will still be on the daily routing problem. This is an area requiring further research. The software system must be able to schedule all routine patients within their time limits, as well as scheduling urgent and priority patients with their more restrictive time limits. Obviously, it is not possible to deliver all patients to their final destination in one day. Therefore, the software would have to use a weighting system; that is, the longer a patient is in the system, the more important it is to deliver him to his destination.

Another possible research effort involving the daily routing problem involves formulating a heuristic algorithm that quickly and efficiently includes the precedence constraints. It has been shown that the exact solution for the precedence-constrained routing problem would involve a very large number of equations, variables, or

both. Therefore, this area routing would indeed benefit from further research.

Finally, a research effort could be undertaken to improve the actual pick-up of patients. It may be possible to use a set-covering approach to picking up the patient. This may require patients, who are capable, to be transported to a central node. The AES aircraft would then pick-up and deliver patients from these fewer nodes.

This would be similar to the hub approach used by many civilian airlines and delivery companies. The aircraft would be assigned to the various regions similar to how they are currently being assigned. However, the aircraft would make fewer stops by going to a predetermined set of airfields. These airfields would be located so that patients surrounding the airfield could be transported to the AES aircraft in minimum time. It will not be possible to handle all patients in this manner since some require special handling, but it would be possible to use the airfields nearest these types of patients as the central hub.

Appendices:

All the data contained in the following appendices has been obtained from the Patient Airlift Center (PAC) and the AES which are located at Scott AFB.

APPENDIX A

Patient Demand Matrices (PDMs) for 1 Year Time Period
from 1 July 87 to 30 June 88

Table XI

PDM for Monday

Region	1	2	3	4	5	6	Total
1	7.58	2.87	0.08	0.37	0.63	0.92	12.45
2	1.90	6.10	0.08	0.56	2.23	0.71	11.58
3	0.08	0.00	6.98	0.40	0.79	1.44	9.69
4	0.08	0.10	0.08	3.85	1.15	0.33	5.59
5	1.40	3.67	1.12	3.81	7.00	2.52	19.52
6	1.81	0.65	1.71	0.25	3.54	12.50	20.46

Table XII

PDM for Tuesday

Region	1	2	3	4	5	6	Total
1	14.42	6.25	0.15	1.27	2.21	2.83	27.13
2	5.75	24.35	0.21	0.81	4.23	0.98	36.33
3	0.31	0.54	7.87	2.13	2.19	21.21	34.25
4	0.96	1.00	2.98	4.62	12.52	1.81	23.89
5	2.15	6.15	1.92	3.75	20.15	6.42	40.54
6	0.98	0.67	23.02	0.38	3.17	1.96	30.18

Table XIII

PDM for Wednesday

Region	1	2	3	4	5	6	Total
1	8.56	10.38	0.25	1.19	2.38	2.81	25.57
2	9.96	11.28	0.38	0.64	6.87	1.09	30.22
3	0.04	0.04	1.21	9.23	0.98	0.72	12.22
4	0.57	0.57	0.34	21.42	2.47	0.81	26.18
5	1.92	4.57	1.42	5.09	9.26	2.49	24.75
6	4.45	1.83	1.53	0.81	3.34	7.45	19.41

Table XIV

PDM for Thursday

Region	1	2	3	4	5	6	Total
1	9.85	4.87	0.21	0.74	1.64	3.19	20.50
2	2.81	12.79	0.11	2.00	2.81	0.92	21.44
3	0.19	0.30	1.75	0.13	1.08	14.38	17.83
4	1.08	2.04	1.77	15.15	4.02	0.85	24.91
5	1.40	6.15	1.98	2.58	20.85	2.87	35.83
6	1.15	0.77	14.42	0.30	2.55	2.51	21.70

Table XV

PDM for Friday

Region	1	2	3	4	5	6	Total
1	14.77	9.15	0.27	1.02	3.29	3.79	32.29
2	10.52	28.31	0.40	2.42	6.56	1.69	49.90
3	0.31	0.54	6.13	0.40	3.06	1.27	11.71
4	0.81	0.48	11.27	17.54	9.23	0.42	39.75
5	2.65	6.23	2.04	5.88	15.12	3.56	35.48
6	6.71	2.65	1.81	1.81	2.85	15.92	31.75

Table XVI

PDM for Saturday

Region	1	2	3	4	5	6	Total
1	4.62	0.67	0.08	0.04	0.65	0.46	6.52
2	3.13	7.56	0.21	0.46	6.65	1.27	19.28
3	0.30	0.15	14.52	5.38	2.40	1.71	24.46
4	0.45	0.30	0.15	5.71	2.23	0.23	9.07
5	0.72	2.35	1.13	1.48	13.40	2.31	21.39
6	1.33	0.62	1.31	0.42	3.90	2.60	10.18

Table XVII

PDM for Sunday

Region	1	2	3	4	5	6	Total
1	0.54	0.33	0.04	0.06	0.06	0.17	1.20
2	15.02	2.56	0.04	0.12	0.63	0.31	18.68
3	0.00	0.00	0.58	0.02	0.08	0.13	0.81
4	1.40	2.94	0.06	0.85	1.35	0.40	7.00
5	0.04	0.11	0.06	0.08	0.69	0.04	1.02
6	0.32	0.17	0.15	0.02	0.11	0.43	1.20

APPENDIX B

Patient Demand Matrices (PDMs) for 3 Month Time Period from 1 March 88 to 31 May 88 (Spring)

Table XVIII

PDM for Monday

Region	1	2	3	4	5	6	Total
1	8.62	3.00	0.00	0.23	0.92	1.08	13.85
2	1.46	4.69	0.08	1.00	2.46	0.85	10.54
3	0.08	0.00	9.00	0.31	1.31	1.00	11.70
4	0.08	0.00	0.15	3.46	0.92	0.38	4.99
5	1.38	4.00	1.15	3.85	7.08	2.31	19.77
6	1.69	1.15	1.38	0.08	3.23	13.38	20.91

Table XIX

PDM for Tuesday

Region	1	2	3	4	5	6	Total
1	15.07	5.57	0.07	1.14	1.57	2.57	25.99
2	6.29	24.57	0.14	1.29	3.00	1.07	36.36
3	0.07	0.21	7.36	0.93	1.36	18.64	28.57
4	1.00	1.14	3.79	3.43	12.86	1.50	23.72
5	1.86	5.86	2.21	4.43	19.21	6.79	40.36
6	1.21	0.50	19.79	0.29	2.64	1.71	26.14

Table XX

PDM for Wednesday

Region	1	2	3	4	5	6	Total
1	8.15	11.23	0.31	1.77	3.00	3.08	27.54
2	10.00	10.38	0.46	0.54	6.77	0.69	28.84
3	0.00	0.08	1.00	9.15	1.62	0.00	11.85
4	0.69	0.92	0.46	22.69	2.15	0.62	27.53
5	2.23	2.85	1.54	7.08	8.92	1.92	24.54
6	3.77	1.31	1.62	0.69	5.00	8.08	20.47

Table XXI

PDM for Thursday

Region	1	2	3	4	5	6	Total
1	12.31	5.46	0.08	0.92	2.15	2.69	23.61
2	2.92	14.00	0.00	2.15	2.85	0.85	22.77
3	0.15	0.23	1.31	0.08	1.23	17.31	20.31
4	2.08	2.46	2.46	16.69	5.62	1.85	31.16
5	1.46	6.62	1.62	2.62	24.38	2.85	39.55
6	0.92	0.62	15.00	0.46	2.38	2.23	21.61

Table XXII

PDM for Friday

Region	1	2	3	4	5	6	Total
1	15.46	10.38	0.08	0.85	3.54	3.69	34.00
2	13.38	32.38	0.62	3.38	6.31	1.92	57.99
3	0.46	0.38	7.85	0.46	3.77	1.46	14.38
4	0.92	0.38	10.62	16.77	8.23	0.46	37.38
5	2.00	7.00	2.38	6.46	15.38	3.69	36.91
6	6.23	3.85	1.92	1.38	1.46	16.77	31.60

Table XXIII

PDM for Saturday

Region	1	2	3	4	5	6	Total
1	4.00	0.62	0.08	0.00	0.54	0.46	5.70
2	3.62	6.85	0.08	0.23	6.38	1.31	18.47
3	0.31	0.08	17.00	6.46	2.38	1.54	27.77
4	0.08	0.15	0.08	5.38	1.77	0.23	7.69
5	0.38	1.77	1.46	0.92	12.77	1.77	19.07
6	1.85	0.62	1.23	0.54	4.23	2.62	11.09

Table XXIV

PDM for Sunday

Region	1	2	3	4	5	6	Total
1	0.46	0.23	0.00	0.00	0.00	0.08	0.77
2	15.92	2.38	0.00	0.00	0.54	0.62	19.46
3	0.00	0.00	0.08	0.00	0.00	0.00	0.08
4	0.92	1.46	0.00	0.77	1.62	0.62	5.39
5	0.00	0.00	0.08	0.15	0.62	0.08	0.93
6	0.00	0.00	0.23	0.00	0.00	0.38	0.61

APPENDIX C

Patient Demand Matrices (PDMs) for 3 Month Time Period from 1 June 88 to 30 June 88 and from 1 July 87 to 31 August 87 (Summer)

Table XXV

PDM for Monday

Region	1	2	3	4	5	6	Total
1	7.92	3.38	0.15	0.54	0.92	1.38	14.29
2	2.00	7.08	0.08	0.46	2.23	0.92	12.77
3	0.15	0.00	7.00	0.92	1.15	2.46	11.68
4	0.08	0.08	0.00	4.54	1.08	0.31	6.09
5	1.46	3.85	1.54	3.69	6.77	2.54	19.85
6	2.31	0.38	2.85	0.54	4.08	11.31	21.47

Table XXVI

PDM for Tuesday

Region	1	2	3	4	5	6	Total
1	16.00	7.08	0.33	0.92	2.33	2.83	29.49
2	6.25	24.42	0.17	0.50	4.33	0.83	36.50
3	0.42	0.92	7.17	1.17	3.08	22.17	34.93
4	0.50	0.17	2.58	3.67	13.67	1.58	22.17
5	2.83	6.50	1.17	4.50	23.17	6.50	44.67
6	1.08	0.67	23.75	0.42	3.92	2.83	32.67

Table XXVII

PDM for Wednesday

Region	1	2	3	4	5	6	Total
1	9.57	10.50	0.43	1.14	2.29	2.50	26.43
2	11.21	10.57	0.29	0.71	7.14	1.21	31.13
3	0.00	0.00	0.57	8.43	0.64	0.29	9.93
4	0.43	0.29	0.21	19.21	2.21	0.86	23.21
5	2.14	5.71	1.57	4.00	9.50	2.79	25.71
6	3.93	1.93	1.64	0.07	3.07	7.07	17.71

Table XXVIII

PDM for Thursday

Region	1	2	3	4	5	6	Total
1	7.79	4.93	0.21	0.57	1.29	2.93	17.72
2	2.29	12.43	0.14	2.43	2.43	0.79	20.51
3	0.21	0.28	1.36	0.00	1.36	11.14	14.35
4	0.79	1.43	1.07	15.14	3.79	0.57	22.79
5	1.43	5.79	2.07	2.86	18.57	3.71	34.43
6	1.14	0.64	11.00	0.21	3.21	2.79	18.99

Table XXIX

PDM for Friday

Region	1	2	3	4	5	6	Total
1	13.00	8.77	0.23	0.85	3.38	4.62	30.85
2	11.38	28.69	0.23	2.69	6.31	1.15	50.45
3	0.38	0.54	6.15	0.31	2.54	0.85	10.77
4	0.77	0.38	13.31	19.23	10.54	0.77	45.00
5	3.23	5.69	2.46	6.38	16.23	3.62	37.61
6	7.38	1.92	1.92	2.46	3.54	14.08	31.30

Table XXX

PDM for Saturday

Region	1	2	3	4	5	6	Total
1	4.92	0.46	0.00	0.15	0.77	0.31	6.61
2	3.62	8.69	0.23	0.31	7.31	1.00	21.16
3	0.46	0.23	11.92	5.31	2.00	2.31	22.23
4	0.38	0.62	0.08	5.69	2.69	0.38	9.84
5	1.00	2.15	0.69	2.31	15.31	1.92	23.38
6	1.54	0.69	1.08	0.38	3.00	3.08	9.77

Table XXXI

PDM for Sunday

Region	1	2	3	4	5	6	Total
1	0.62	0.08	0.08	0.08	0.08	0.08	1.02
2	15.23	3.31	0.00	0.31	0.62	0.15	19.62
3	0.00	0.00	0.38	0.00	0.15	0.08	0.61
4	1.85	4.77	0.15	0.85	1.31	0.31	9.24
5	0.00	0.08	0.00	0.08	0.62	0.08	0.86
6	0.38	0.15	0.08	0.00	0.15	1.08	1.84

APPENDIX D

Patient Demand Matrices (PDMs) for 3 Month Time Period
from 1 September 87 to 30 November 87 (Fall)

Table XXXII

PDM for Monday

Region	1	2	3	4	5	6	Total
1	6.23	2.77	0.08	0.54	0.62	1.15	11.39
2	2.23	7.54	0.08	0.46	1.69	0.46	12.46
3	0.08	0.00	4.85	0.23	0.46	1.00	6.62
4	0.15	0.23	0.08	3.93	0.93	0.08	5.40
5	1.38	3.54	0.85	4.54	6.77	2.85	19.93
6	1.15	0.69	1.08	0.31	3.23	13.00	19.46

Table XXXIII

PDM for Tuesday

Region	1	2	3	4	5	6	Total
1	14.23	7.31	0.23	1.92	2.54	3.38	29.61
2	5.54	25.54	0.23	0.85	4.54	0.92	37.62
3	0.31	0.23	9.46	2.54	2.54	22.00	37.08
4	0.92	0.85	2.77	7.00	11.15	2.38	25.07
5	1.92	6.15	2.31	2.31	19.46	6.23	38.38
6	0.85	0.92	26.46	0.38	3.08	2.15	33.84

Table XXXIV

PDM for Wednesday

Region	1	2	3	4	5	6	Total
1	8.00	9.54	0.23	0.85	2.08	2.85	23.55
2	9.69	14.69	0.31	0.69	7.54	1.08	34.00
3	0.15	0.08	1.92	9.46	1.15	1.62	14.38
4	0.69	0.54	0.08	22.92	3.00	0.85	28.08
5	2.00	4.00	1.08	4.15	9.15	2.31	22.69
6	5.31	2.00	1.38	0.85	2.23	6.31	18.08

Table XXXV

PDM for Thursday

Region	1	2	3	4	5	6	Total
1	8.92	4.31	0.31	1.00	1.77	3.85	20.16
2	3.62	13.46	0.08	2.08	2.85	0.85	22.94
3	0.15	0.38	2.54	0.38	1.15	14.15	18.75
4	1.08	2.92	1.31	13.38	3.15	0.38	22.22
5	1.31	5.85	2.31	2.31	18.31	2.38	32.47
6	1.31	1.15	14.08	0.46	2.23	2.38	21.61

Table XXXVI

PDM for Friday

Region	1	2	3	4	5	6	Total
1	16.15	10.46	0.54	1.00	4.00	3.23	35.38
2	8.69	28.31	0.38	1.08	6.15	1.77	46.38
3	0.23	0.62	3.92	0.62	3.15	1.77	10.31
4	0.85	0.54	11.00	17.85	8.46	0.31	39.01
5	2.77	5.85	1.77	5.00	14.62	4.15	34.16
6	7.00	2.92	1.85	1.38	3.23	16.69	33.07

Table XXXVII

PDM for Saturday

Region	1	2	3	4	5	6	Total
1	5.38	0.54	0.08	0.00	0.92	0.46	7.38
2	2.54	7.23	0.15	0.46	6.23	1.54	18.15
3	0.31	0.08	14.54	4.62	2.31	1.46	23.32
4	0.92	0.46	0.23	6.54	2.38	0.15	10.68
5	0.77	3.08	1.08	1.46	13.38	2.31	22.08
6	1.08	0.38	1.23	0.23	4.23	2.62	9.77

Table XXXVIII

PDM for Sunday

Region	1	2	3	4	5	6	Total
1	0.46	0.54	0.08	0.15	0.08	0.46	1.77
2	17.38	2.15	0.08	0.15	1.00	0.38	21.14
3	0.00	0.00	1.00	0.00	0.08	0.38	1.46
4	2.15	3.69	0.00	0.38	1.00	0.23	7.45
5	0.08	0.15	0.15	0.08	0.85	0.00	1.31
6	0.23	0.38	0.08	0.08	0.15	0.08	1.00

APPENDIX E

Patient Demand Matrices (PDMs) for 3 Month Time Period from 1 December 87 to 29 February 88 (Winter)

Table XXXIX

PDM for Monday

Region	1	2	3	4	5	6	Total
1	7.54	2.31	0.08	0.15	0.08	0.08	10.24
2	1.15	5.08	0.08	0.31	2.54	0.62	9.78
3	0.00	0.00	7.08	0.15	0.23	1.31	8.77
4	0.00	0.08	0.08	3.46	1.69	0.54	5.84
5	0.77	3.31	0.92	3.15	7.38	2.38	17.91
6	2.08	0.38	1.54	0.08	3.62	12.31	20.01

Table XL

PDM for Tuesday

Region	1	2	3	4	5	6	Total
1	12.46	5.15	0.00	1.08	2.46	2.54	23.69
2	4.92	22.85	0.31	0.54	5.31	1.08	35.01
3	0.46	0.85	7.46	3.92	1.92	22.38	36.99
4	1.38	1.77	2.69	4.38	12.46	1.77	24.45
5	2.08	6.15	1.92	3.77	19.08	6.15	39.15
6	0.77	0.62	22.38	0.46	3.15	1.23	28.61

Table XLI

PDM for Wednesday

Region	1	2	3	4	5	6	Total
1	8.46	10.23	0.00	1.00	2.15	2.85	24.69
2	8.85	9.54	0.46	0.62	6.00	1.38	26.85
3	0.00	0.00	1.38	9.92	0.54	0.31	12.15
4	0.46	0.54	0.62	21.00	2.54	0.92	26.08
5	1.31	3.31	1.46	5.23	9.46	2.92	23.69
6	4.85	2.08	1.46	0.77	3.08	8.38	20.62

Table XLII

PDM for Thursday

Region	1	2	3	4	5	6	Total
1	10.54	4.77	0.23	0.46	1.38	3.31	20.69
2	2.46	11.31	0.23	1.31	3.15	1.23	19.69
3	0.23	0.31	1.85	0.08	0.54	15.15	18.16
4	0.38	1.38	2.31	15.38	3.54	0.62	23.61
5	1.38	6.38	1.92	2.54	22.31	2.46	36.99
6	1.23	0.69	17.85	0.08	2.31	2.62	24.78

Table XLIII

PDM for Friday

Region	1	2	3	4	5	6	Total
1	14.46	7.00	0.23	1.38	2.23	3.62	28.92
2	8.69	23.85	0.38	2.54	7.46	1.92	44.84
3	0.15	0.62	6.62	0.23	2.77	1.00	11.39
4	0.69	0.62	10.15	16.31	9.69	0.15	37.61
5	2.62	6.38	1.54	5.69	14.23	2.77	33.23
6	6.23	1.92	1.54	2.00	3.15	16.15	30.99

Table XLIV

PDM for Saturday

Region	1	2	3	4	5	6	Total
1	4.15	1.08	0.15	0.00	0.38	0.62	6.38
2	2.77	7.46	0.38	0.85	6.69	1.23	19.38
3	0.15	0.23	14.62	5.15	2.92	1.54	24.61
4	0.46	0.00	0.23	5.23	2.08	0.15	8.15
5	0.77	2.38	1.31	1.23	12.15	3.23	21.07
6	0.85	0.77	1.69	0.54	4.15	2.08	10.08

Table XLV

PDM for Sunday

Region	1	2	3	4	5	6	Total
1	0.62	0.46	0.00	0.00	0.08	0.08	1.24
2	11.54	2.38	0.08	0.00	0.38	0.08	14.46
3	0.00	0.00	0.85	0.08	0.08	0.08	1.09
4	0.69	1.85	0.08	1.38	1.46	0.46	5.92
5	0.08	0.23	0.00	0.08	0.69	0.00	1.08
6	0.69	0.15	0.23	0.00	0.15	0.23	1.45

Bibliography

1. Air University. Toward a Healthier Aeromedical Operation. Research Report AU-ARI-86-9. Air University Press (July 1980).

2. Beasely, J.E. "Fixed Routes," Journal of Operational Research Society, 35: 49-55 (1984).

3. Christofides, N. and J.E. Beasely. "The Period Routing Problem," Networks, 14: 237-256 (1984).

4. Current, J.R., C.S. Revelle and J.L. Cohon. "The Maximum Covering/Shortest Path Problem: A Multi-objective Network Design and Routing Formulation," European Journal of Operational Research, 21: 189-199 (August 1985).

5. Donnelly, M. Personal Correspondance. HQ MAC/AGA, Scott AFB, Illinois, June 1988.

6. Flood, M.M. "The Traveling Salesman Problem," Operations Research, 4: 61-75 (1956).

7. Garcia-Diaz, Alberto. "A Heuristic Circulation-Network Approach to Solve the Multi-Traveling Salesman Problem," Networks, 15: 455-467 (Winter 1985).

8. Golden, B.L., T.L. Magnanti and H.Q. Nguyen. "Implementing Vehicle Routing Algorithms," Networks, 7: 113-148 (1977).

9. Held, M., A.J. Hoffman, E.L. Johnson and P. Wolfe. "Aspects of the Traveling Salesman Problem," IBM Journal of Research and Development, 28: 476-486 (July 1984).

10. Hillier, F.S. "Heuristics: A Gambler's Roll," Interfaces, 13: 9-12 (3 June 1983).

11. Kalantari, B., A.V. Hill and S.R. Arora. "An Algorithm for the Traveling Salesman Problem with Pick Up and Delivery Customers," European Journal of Operational Research, 22: 377-386 (December 1985).

12. Laporte, G., Y. Nobert and M. Desrochers. "Optimal Routing under Capacity and Distance Restrictions," Operations Research, 33: 1050-1073 (September-October 1985).

13. Lev, B. and E. Kwatney. "Simulation of a Regional Scheduling Problem," Interfaces, 18: 28-37 (March-April 1988).

14. McLain, D.R. A Systems Approach to the Aeromedical Aircraft Routing Problem using a Computer Based Model. PhD dissertation. University of California, Berkeley, 1984.

15. Russel, R. and W. Igo. "an Assignment Routing Problem," Networks, 9: 1-17 (1979).

16. Skitt, R.A. and R.R. Levary. "Vehicle Routing via Column Generation," European Journal of Operational Research, 21: 65-76 (July 1985).

Vita

W. Tod Whetstone [redacted] in 1981 [redacted] attended the University of Notre Dame from which he received the degree of Bachelor of Science in Aerospace Engineering. He received his commission in the USAF through the ROTC program. He completed missile training as a Distinguished Graduate and received his missile badge in October 1985. He then served as a Deputy Missile Combat Crew Commander in the 509th Strategic Missile Squadron, Whiteman AFB, Missouri. He then served as a missile instructor and missile procedures trainer operator at Whiteman AFB until entering the School of Engineering, Air Force Institute of Technology, in June 1987.

[redacted]